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Vol. 195 FEBRUARY, 1923 No. 2

RECENT AERONAUTIC INVESTIGATIONS AND THE AIRPLANE INDUSTRY.*

BY

JOSEPH S. AMES, Ph.D., LL.D.

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EVERY industry concerned with manufacture relies upon the work of the scientist for the knowledge which makes its existence possible. Progress in the industry may come from increased efficiency in method, from improvements based upon existing knowledge or from new knowledge furnished by scientific laboratories. This last fact is obvious. It is even realized by those who control the industries. Many of our largest manufacturing companies support research laboratories where work of the truest scientific character is carried on, in which the investigators are forbidden to consider the possible practical applications of the fruit of their labor. These enlightened companies know that what is most needed and what is the most difficult to obtain is a continuous increase of knowledge of new facts, new phenomena concerning electricity, radiation, chemical reactions, and, in reality, all nature. The men who can do this research work are not easily found, while those who can apply the new knowledge to practical purposes abound. It happens but rarely that a man has

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the ability and patience required to devise and carry on scientific investigations and at the same time can elaborate the processes to make his discoveries useful. A man cannot serve two masters. The worker in pure science, as it has been called, gets his reward from having added to the store of truth vouchsafed to man; and, if his mind runs at times along more practical lines, he may rest assured that there is no scientific discovery, however remote, seemingly, from the processes of daily life, which may not ultimately be made use of in some commercial industry.

An industry which is essentially modern and which is growing in importance daily is that associated with aviation. During the war we saw it grow to manhood from the condition of a baby in an incubator. But the full-grown man was like an athlete developed for a specific purpose. Airplanes for all kinds of military operations were perfected, to such a degree that to most of us to-day an airplane means but one thing, a weapon for war. It is true that those of us who are interested in sports look upon one also as a racing machine, and the fact that danger is associated with the sport makes it for many people all the more interesting. Now, as long as people consider aviation only from the standpoint of warfare or sport, the country as a whole is not interested. This is a fact which should be realized by all who see in aviation greater possibilities. It does obviously offer a method of transportation which when developed will revolutionize our lives as much as the automobile has done in our generation or the steam railroads and steam vessels did in that of our fathers and grandfathers. Before this day can come, however, each of us must be made to realize what aviation will mean to him personally, each day of his life. An airplane as a war machine or as a sporting toy does not concern us, and we will not think seriously about the subject.

As a commercial enterprise, aviation is, however, increasing in importance; and it is one of those industries whose reliance upon scientific investigations is direct and complete. In the years before the war airplanes had been made and flown in sporting events, and it is interesting for an American to recall that the whole science and art are based upon the work of three of our countrymen: Langley and the Wright brothers. Few of us in this country, though, had a vision of the possibilities of aviation; but in Europe it was different. England had a group of men

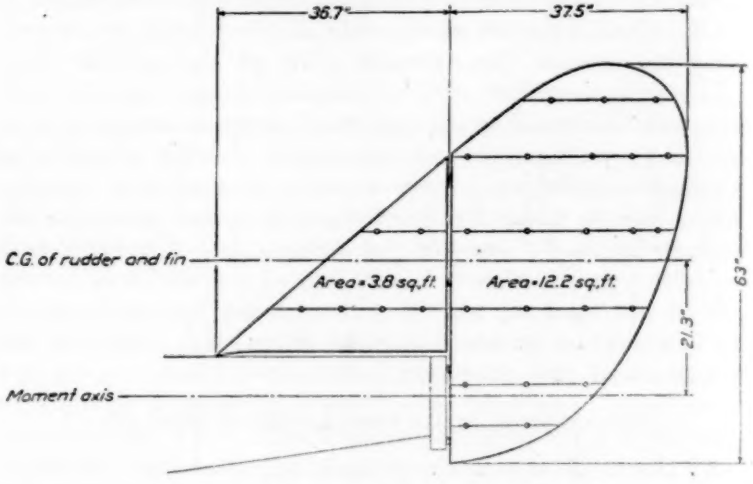
developing its theoretical features and also performing well-planned experiments in a laboratory maintained by the Government. In France the great engineer Eiffel was carrying on a beautiful series of experiments in a fine laboratory of his own. In Germany Prandtl and others were also at work. So when, at the very outset of the war, the possibilities of aviation became apparent, and as the days went on, its predominating importance was recognized, the European countries had at their disposal a considerable amount of scientific information which could be put to practical use immediately. This was done and this is the explanation of the seemingly magical expansion of aviation.

One effect of the war was to make all countries, even our own, realize the need of the intensive study of the scientific facts underlying aeronautics. The only limitation upon this has been the earnest desire of certain governments to economize, for all laboratory investigations are expensive. In this country the government maintains an aerodynamic laboratory at Langley Field, Virginia, under the direct supervision and control of the National Advisory Committee for Aeronautics. The work done here is of a purely scientific nature but, as has been said, no new facts of this kind are learned without being applied sooner or later to a practical purpose. In what follows will be given a few illustrations of this statement:

I. DISTRIBUTION OF AIR FORCES OVER AN AIRPLANE.

As every one knows, an airplane is heavier than air and is sustained in flight owing to the dynamical action of the air flowing past its wings, there being produced an increased pressure below the wings and a decreased pressure above. The upward force due to these pressure differences is called the "lift," and it is of interest to note that the greater part of the lift is due to the diminished pressure on the upper side of the wings, so that one may say an airplane is pulled rather than pushed up. Similarly, due to the rapid flow of air there are forces on all the other parts of the airplane: The fuselage, the rudder, the elevator, the stabilizing surface at the rear and the fins. When the airplane is in steady horizontal flight, these forces have certain values; when the airplane is manœuvring, performing a loop, a roll, a dive, etc., all of them change. Further, if the shape or size of any part is altered, the forces are also changed. It is obvious that before

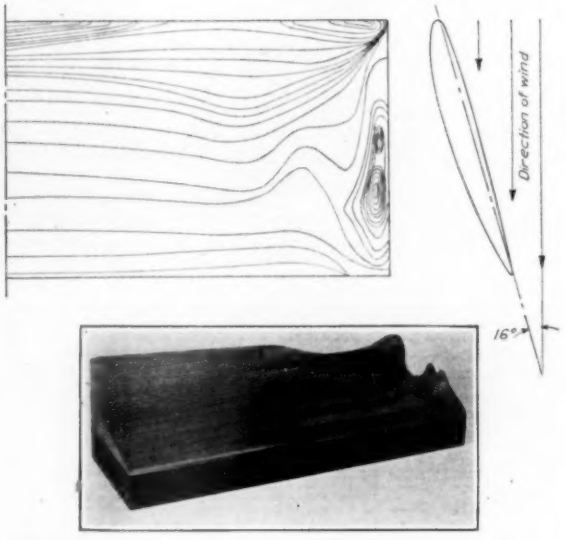
one can design the structure of an airplane or before any satisfactory theory of the behavior of an airplane can be worked out, it is necessary to know the intensity of these forces. It is not sufficient, however, to know the total force acting on a wing, for instance; one must also know how this force is distributed: Is the greater part experienced near one edge or the other? Are there any special areas where the force is greater than at others? Further, how is this distribution affected, by making the airplane manœuvre or by changing the shapes of its various parts? In order to answer these questions, a long series of experiments



Elevation of fin and rudder showing location of holes.

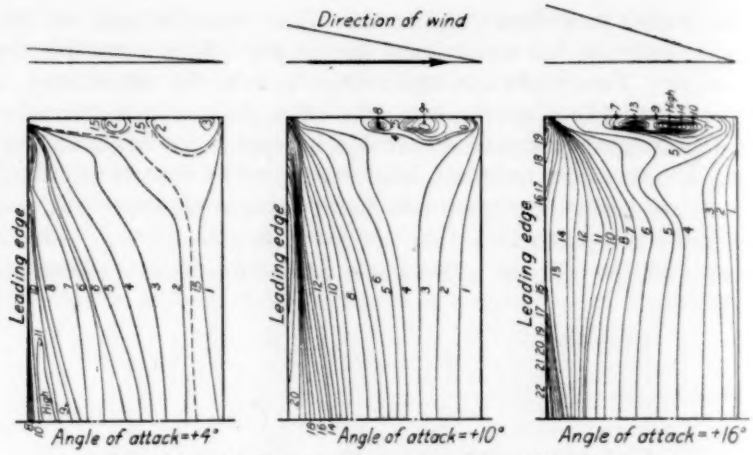
has been carried out both upon models of airplanes held suspended in a wind-tunnel and upon airplanes in actual flight. The same method is used in both sets of experiments. A series of small holes is made in the surface of the part to be investigated; each of these is connected by a rubber tube to a central instrument, which really is a number of separate instruments, each of which measures the pressure of the air in one tube; the indications of these instruments are photographed simultaneously. By this method the pressures existing at any instant at twenty-five or thirty points of the wing, or whatever part is in question, may be determined. By connecting the apparatus to various parts of an airplane, the distribution of the force, under any specific cir-

cumstances, may thus be learned. The essential part of the whole device is, of course, the instrument which measures the pressure. Two types are used: One, in case the experiment is upon a model in a wind-tunnel; the other, in case of an airplane in flight. Both instruments are special types of what are called "manometers" in technical laboratories. The former is simply a series of glass tubes, each tube has a basin at its lower end, and the latter and part of the tube is filled with a liquid, *e.g.*, colored alcohol; if the pressure at the lower end of any tube is increased,

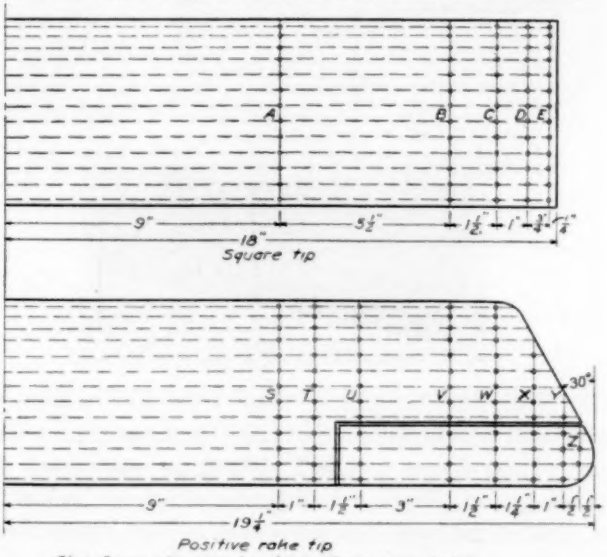


Contour model of loads on square tip wing at 16° angle of attack. Neutral aileron.

the liquid will rise higher in the tube; if the pressure is lowered, the level of the liquid will fall. Such an instrument could not well be used in an airplane in flight or when making a loop or a roll; so a different type was perfected. This consists essentially of a thin metal diaphragm, held stretched in a metal frame in a closed case, to one side of which is connected the rubber tube leading to the opening in the wing. If the air pressure in this tube increases, the diaphragm will bulge out on the opposite side, while if the pressure decreases, it will bulge in. All that is necessary is to record these slight bending motions of the diaphragm. This is done by attaching to it a small mirror from which a beam of

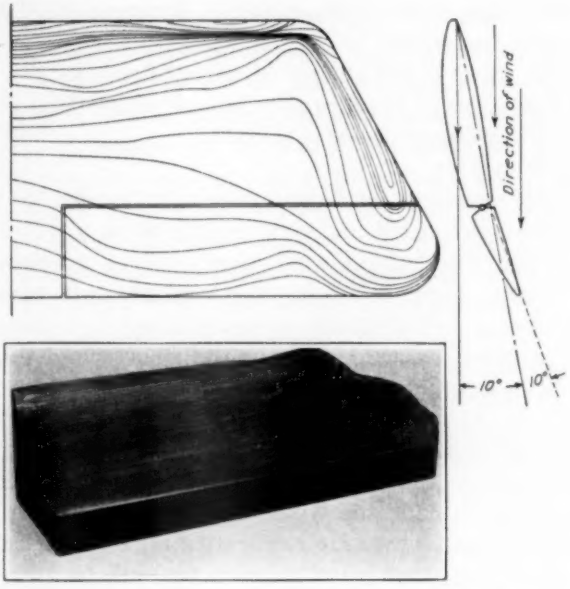


Plan views with contour lines showing pressure variation with angle of attack.

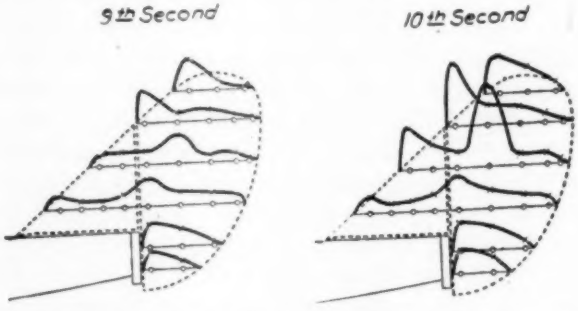


Plan forms showing location of pressure holes

light is reflected onto a photographic film; when the diaphragm is bulged out or in, the mirror is of course rotated in one direction or the other, and so the beam of light is deflected one way or the other. Before any such manometer may be used for measurements it must, of course, be standardized by subjecting it to known pressures and measuring their effect. If the central recording



Contour of loads on wing, with positive rake at 10° angle of attack. Aileron 10° down.



Showing the curves of pressures over the entire surface of the rudder and fin for various intervals of time during a left turn.

instrument has several such manometers it is convenient to adjust them so that they are equally sensitive. This facilitates the interpretation of the photographic records. Little more need be said in regard to the method used in this investigation. The results obtained are most interesting. In a field of study as extensive as this, I am compelled to make a selection; and the cases I shall discuss are as follows:

(1) The case of an ordinary wing, showing the "peak" of pressure near one corner.

(2) The effect of the change of angle of attack.

(3) The effect of changing the plan form of the wing.

(4) The influence of the aileron.

(5) The rudder.

All these cases can be described best by models or by topographic drawings. Each model corresponds to a relief map of a country, the elevation at each point being a measure of the pressure at that point, this being the total pressure upward, due to the combined action at the upper and lower surfaces. The principal features are evident from the figures and do not call for explicit description.

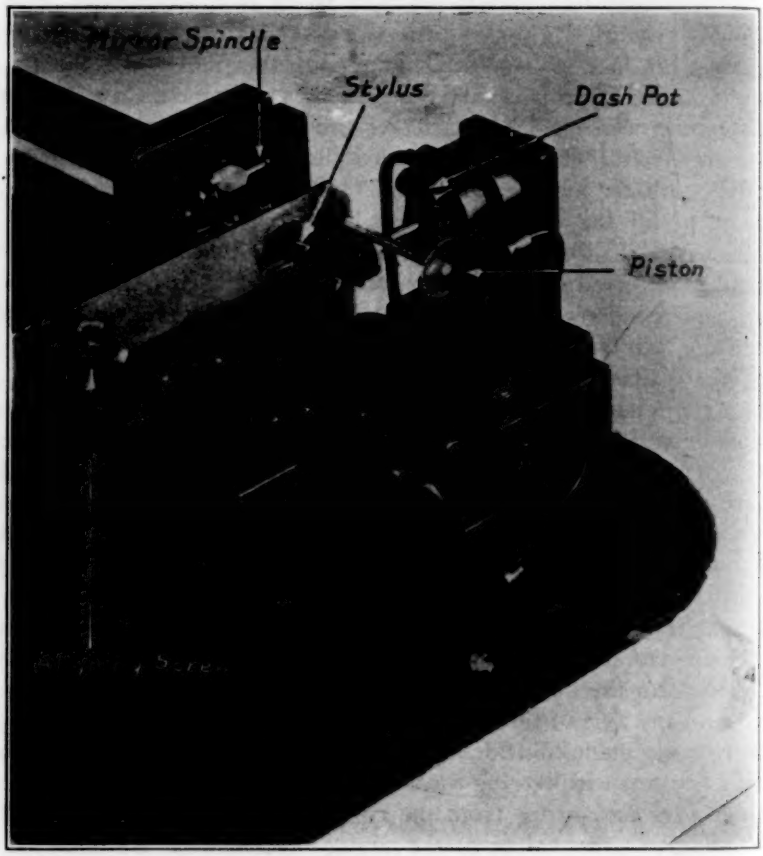
Many of the facts brought out in this investigation were entirely unexpected, and all the results are of great importance to one interested in the science of aerodynamics. But to the designer of an airplane the whole series of investigations is of fundamental importance. He can learn first of all what type of wing to adopt, and then what relative strength to give different parts of the structure so as to meet the stresses they will be called upon to stand. In this way he can so plan his machine that it will not be unduly strong at points which do not demand great strength, and thus save cost in material and construction. Further, if it is desired to subject an airplane to loading tests in order to learn accurately its breaking strength, this can now be done intelligently. In the past the custom in making this test has been to turn a wing upside down and put on top bags of sand, increasing the weight of these until the wing broke. No definite way of distributing the sand in order to correspond to actual flying conditions was known, but now it is; and in the future these tests will have a thoroughly practical meaning.

II. THE MOTION OF AN AIRPLANE IN MANŒUVRES.

Another investigation had its origin in the need of the theoretical student of aerodynamics to know the exact motion of an airplane at any instant and the effect on this motion of slight changes in the control surfaces, the rudder, the elevator and the ailerons. In order to describe the motion one must know the motion of the centre of gravity—its velocity and acceleration, and also the angular motions about the three axes, *i.e.*, the angular

velocities and the angular accelerations. Instruments for measuring the velocity of an airplane have been in use for many years. The best types make use of the principle that when air is flowing (or when an object is moving through the air) the pressure felt by a body which stops the air is different from that felt in air at rest, and that this impact pressure, as it is called, varies with the velocity of the air. (Anyone who has felt wind blowing against his face or hand is familiar with this fact.) So the air-speed indicator, as it is called, is an instrument for measuring the difference between the impact pressure and the static pressure of the air; from its readings, recorded photographically, the velocity of the airplane may be calculated. Instruments for the measurement of all the other quantities had to be designed and constructed. The matter is complicated because there are three independent directions in which the centre of gravity of the airplane may move; along the line of the shaft of the propeller, sidewise and up; similarly the machine may rotate about any one (or all) of these lines. Therefore any one instrument must in reality be a combination of three instruments. To measure the acceleration in any one direction use is made of a stiff strip of steel, one of whose ends is rigidly held and whose other end will therefore move as the strip bends under the application of the force due to acceleration; the motion of this free end can be recorded photographically; and after the instrument is calibrated or standardized, a measure is obtained of the acceleration in this particular direction. Three of these instruments, combined so as to measure accelerations along three mutually perpendicular directions, form the necessary accelerometer. If the angular velocity around any axis of the airplane is recorded for any length of time, there being made coincidently accurate records of the time, a curve may be drawn expressing the angular velocity as a function of the time. By measuring from the curve the changes in the former per unit of time, values of the angular acceleration are obtained; and also by integrating the curve, as the process is called, that is by working backwards, one can learn through what angle the airplane has turned at any instant. The essential requirements for the instrument are, then, a recording clock and a device to register angular velocity. For a clock a constant speed electric motor serves, and by means of obvious mechanism a sharp line is photographed every second or every two seconds on a rotating

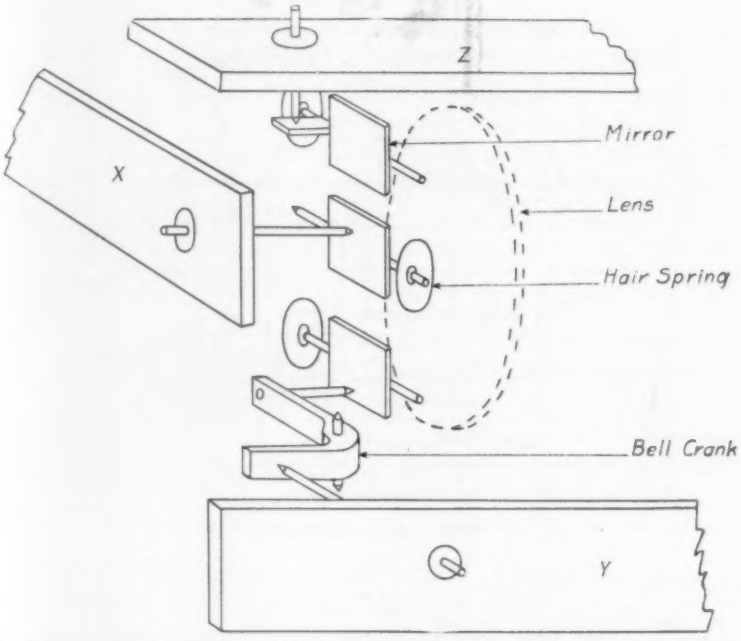
film, superposed upon which are the other records. To measure the angular velocity use is made of a rapidly spinning electric motor mounted as a gyroscope; for, as is well known, if the supports of such a top are rotated around an axis, as would happen in an airplane making manœuvres, the axis of the top itself tends



Three component accelerometer.

to move, this motion can be prevented by applying a suitable force, *e.g.*, by a spring, and the intensity of this force—which depends upon the rate of rotation of the airplane—can be measured by photographing the displacement of the spring. Three such gyroscopes, mounted so as to spin about axes mutually perpendicular, will thus serve to record all of the angular velocities of the air-

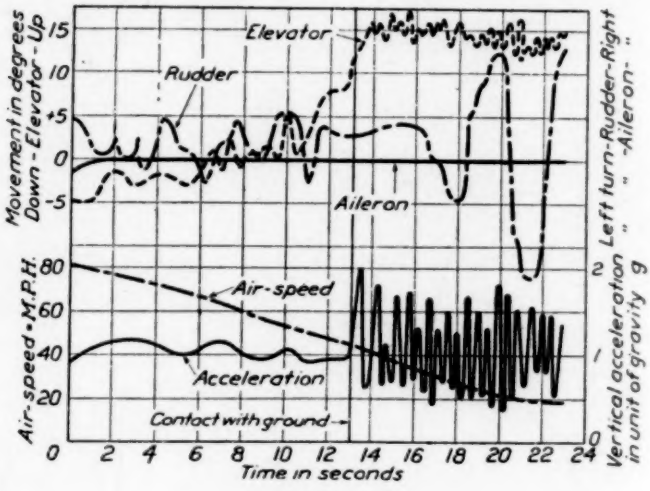
plane, thus forming an angular velocity meter. To complete the instrumental equipment all that is needed is an instrument to record the motions of the controls. This is extremely simple. A wire leads from each control to a small metal spool which can turn on a metal rod, the connection between the two being by screw threads cut on the outer surface of the rod and the inner surface of the spool—just like a bolt and its nut, a tension spring being introduced. The wire from the control is wound around



Three component accelerometer, showing the means for transferring the motion of the springs to the three mirrors. The dash pots are omitted.

the spool and fastened to it; so, if the wire is lengthened or shortened, the spool will turn and at the same time slide along its axial rod, in one direction or the other. This sliding motion can be recorded on a photographic film. There are three of these control motions to be recorded, *viz.*, of the rudder, of the elevator, and of the ailerons; and to distinguish between the three records different types of shutters are introduced in the paths of the rays of light coming from the different sliding spools: One makes a dashed photographic record, one a dot and a dash record, and the

third a continuous one. This, with the necessary storage batteries, completes the apparatus needed for the investigation. The airplane under study is equipped with the instruments, which in reality are very compact and light; and, when a manœuvre begins, as for instance a loop, the pilot simply pushes a button, the electric chronometer begins to operate, the gyroscopes begin to spin, the lights required for making the photographic records flash up, and all is ready. After this, everything is automatic. When the pilot lands his machine, the film is developed and the records are



Three-point landing.

measured and studied. There are, of course, numerous records on any one film after any one manœuvre: The straight lines spaced to give time intervals, the three control records, those giving the three components of the acceleration of the centre of gravity, and finally those giving the three components of the angular velocity—10 records in all. Of course for many simple manœuvres a record is taken of only one component of either the acceleration or the angular velocity; so in general the film records do not look complicated. For nearly all purposes it is found useful to calculate from the curve for angular velocity the curves for angular displacement and angular acceleration and to plot these, together with the curve giving the speed of the airplane, on the same photograph; so that one record gives the entire

history of the manœuvre. I shall show a few records of this kind. There is no need of any detailed description, for each tells its own story completely.

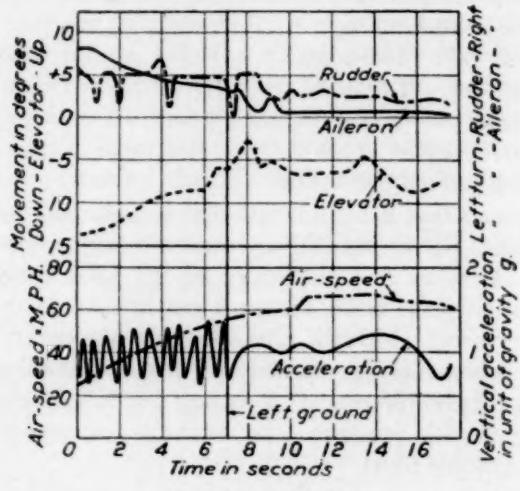
a. Three-point landing.
b. Taking-off. Tail high.
c. Taking-off. Tail low.
d. A loop.
e. A barrel-roll.
f. A longitudinal oscillation.

It is obvious that the information to be obtained from records such as these is of the utmost importance to any student of aerodynamics. Here he has practically all the facts concerning the motion of an airplane under the most varied conditions. In order to know the forces which the pilot exerts on the control stick and rudder bar when making manœuvres, there is attached to these a force-recorder, consisting of a carbon pile whose electric resistance changes with pressure. Its readings are recorded on the same photographic film.

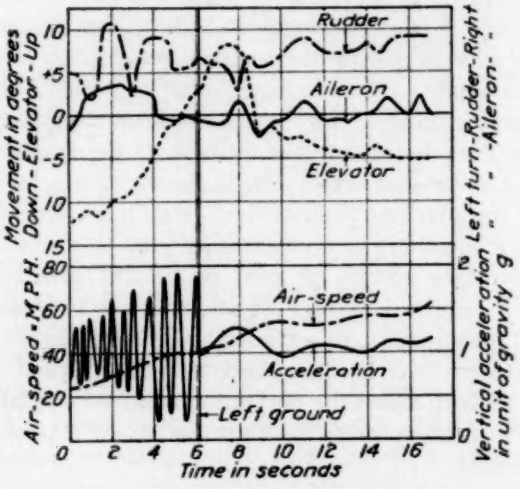
Again there are many purely practical questions which can be answered easily from the knowledge available from these records. Is the machine easily controlled? That is, is the work done by the pilot in moving the controls, in order to produce small changes in attitude of the machine, small or great? The answer may be found instantly. Or, is the machine easily manœuvred? That is, can the pilot change the attitude of the machine rapidly? That again can be answered. Or, is the stability great or small? That is, if the machine is disturbed from a condition of steady flight, as, for instance, by an ascending gust of air, will it return to its steady state quickly or not; or, if the disturbance is too great, will it require a change of the controls to make it return at all? All questions of this kind may be investigated with ease. It is seen that we have here an exact scientific method of learning all that we wish to about the performance of an airplane, nothing is left to the memory or to the impressions of a pilot, it is all a matter of record.

This fact is of the utmost importance in making tests of a new airplane, or of an airplane of a new type. The method in use at present in this country, and in all countries, for carrying out what are called "acceptance tests" of a new airplane, is to send it up in charge of a specially competent pilot, called a "test pilot."

He takes the machine off the ground, flies it steadily, puts it through certain manœuvres, throws it into oscillation, and finally



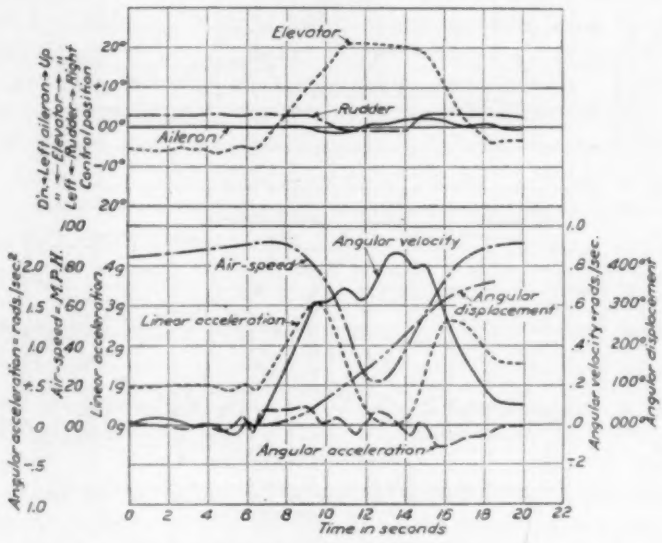
Tail-high "take-off."



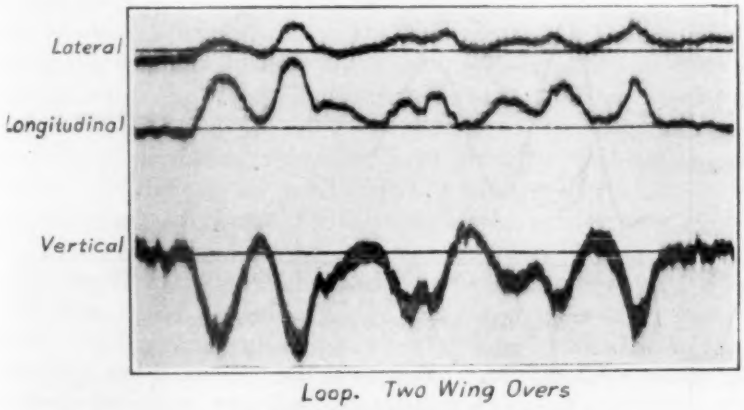
Tail-low "take-off."

lands it. He then makes a report as to his impressions. Upon what he says rests the decision whether the airplane is accepted or rejected. This may be called a practical method, but it is

certainly not scientific. To begin with, every pilot has a preference for some airplane or for the performance of certain airplanes. These he knows and likes. In testing any new machine,



Loop. Angular velocity about Y-axis.

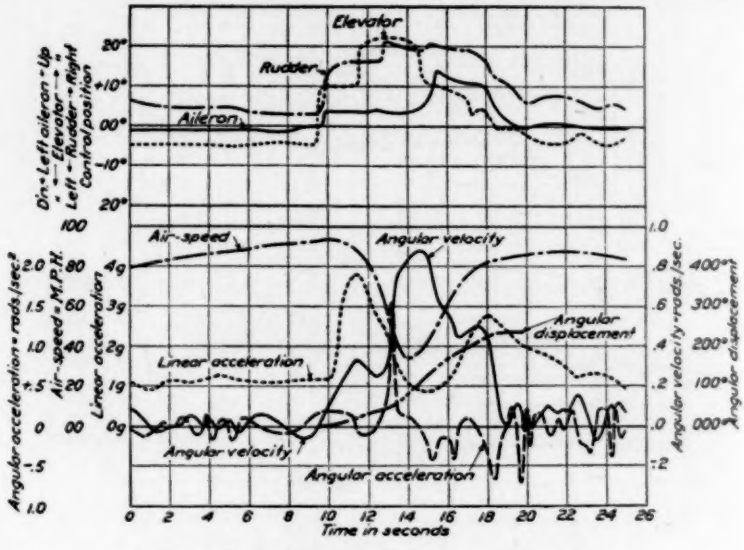


Loop. Two Wing Overs

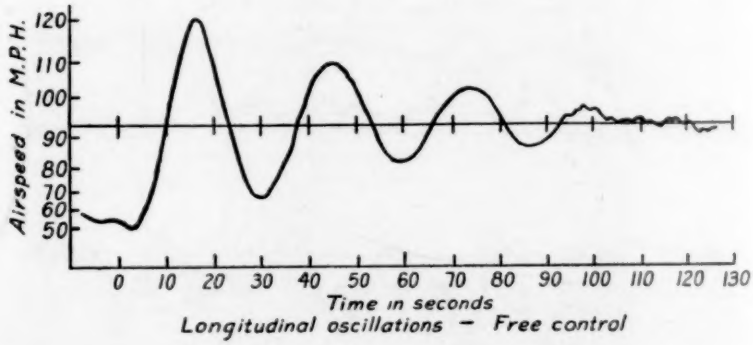
Three component accelerometer records.

he is of necessity comparing it with another to which he is accustomed. The comparison is never altogether fair. Again, all he has to report are impressions, not necessarily facts; and no man

has sufficiently quick perceptions to note all that happens in such a complicated phenomenon as an airplane manœuvre, nor has he a memory sufficiently accurate to recall all that he did observe.



Barrel-roll to right. Angular velocity about X-axis.



The whole method is bad. But up to the present, it has been the best possible. Now, all this is changed. In place of psychological impressions of certain incidents recorded by an imperfect memory by a man who must be prejudiced to a certain degree, we are able to obtain exact photographic records of what occurs at each instant.

Another obvious application of the method is to the training of pilots. As has been said before, an airplane manœuvre takes place so quickly that no pilot knows exactly what he does. If he is skilled and therefore has a good "air sense," he does many things by instinct. If he is asked, when he lands, how he did a certain thing, he cannot always tell, and he can never be definite. He can never tell another pilot exactly what he did. He may know in a general way how it was done, but the second pilot has to go up and learn for himself. All this indefiniteness is now obviated; a pilot can get an exact record of what he did to each control in performing any manœuvre; and this record may be used in instructing a new pilot. Further, pilots will differ in the way in which they effect a loop, a roll or even a landing, and the best of them may learn considerably by comparing his own records with those of other pilots.

III. THE COMPRESSED AIR WIND-TUNNEL.

Aerodynamics is the science which is concerned with the properties of the air in motion, and of solid bodies in motion with reference to the air. The way in which most of our experimental knowledge of the subject has been obtained has been by supporting solid bodies from balances in a large tube through which air is drawn by means of a suction fan. Such an apparatus is called a wind-tunnel. The balances record the forces and moments required to hold the solid body stationary in spite of the action of the rapidly flowing air-stream. Tunnels have been made as large as 10 or 12 feet in diameter, and fans are used capable of producing velocities from 30 miles an hour to over 200. The size of the solid object immersed in the air-stream is controlled, of course, by the size of the tunnel. By experiments of this character an immense amount of data has been accumulated and many empirical laws have been deduced. (Experiments of the same kind could be conducted on other gases if there were a sufficient supply.) It will be noted that in these experiments there are only two quantities which are varied: The size of the solid object to a limited degree and the velocity of the air. It is evident, however, that the forces acting on the solid body depend upon other things than its size and the velocity of the stream of air. It is clear, for instance, that the force must vary with the density of the air. The force we ourselves

experience if we stop a solid ball is much more intense than it is when we catch a hollow ball of the same size. An increase in the density of the air is an increase in its mass, in its inertia; and this would be felt by the solid body in the tunnel. Again, when a solid is immersed in air, a layer of the air sticks tightly to it, so that as the air-stream flows past the body there is friction, not between the surface of the solid and the moving air, but between the latter and the layer of air adhering to the solid body. This force of friction varies then with the viscosity of the gas, the more viscous it is, the greater is the friction. Therefore, to add to our aerodynamical knowledge we should experiment with an apparatus which allows us to vary the density of the gas and also its viscosity. In order to accomplish the first part of this, namely, to vary the density of the gas, the National Advisory Committee for Aeronautics has had constructed a huge steel tank, inside of which is placed a complete wind-tunnel and in which the air can be kept in a state of compression anywhere between one and twenty atmospheres. The viscosity of the air will be changed slightly by this compression, but not sufficiently to enable one to experiment directly upon its influence. With an apparatus of this kind, the only one so far made in the world, a new source of valuable information is available. It will take several years, however, to systematize it and to make full use of it.

The purpose of this compressed air wind-tunnel is not, however, simply that just given. It has been the custom for many years for designers of aircraft to make models of them of a suitable size to be supported in a wind-tunnel and to have them tested under various conditions, in order to learn whether the ideas which they wished to incorporate in their machines really worked out. Further, in all the aerodynamic laboratories of the world there have been systematic experiments on models of different airplane parts, specially wings, so as to furnish information to the designer. It has long been known that the results obtained from such tests were not altogether conclusive or satisfactory. The operation of the actual airplane showed that its performance was not what would have been expected from the preliminary tests. The reason for this is obvious. Why should an airplane flying through the open air have the same properties as a model, one-twentieth the size or smaller, supported in an

air-stream in the same wind-tunnel? Conditions are fundamentally different. The difference is primarily one of size, and so designers have tried to determine what is called the "scale-effect" and make allowance for it. But the difficulty is that the scale-effect is different for different parts and for different conditions. So while the testing of airplane models in wind-tunnels is still the accepted practice, and a very useful one, it is not as satisfactory as it should be. Fortunately the theory of the flow of air past a solid body reveals a way out of the difficulty. It shows that the properties of an actual airplane of 50 feet span, say, while in actual flight, are the same as those of a model of 2 feet span in a wind-tunnel, provided the air in the tunnel is compressed to a pressure of 25 atmospheres. This means that the change in dimensions of the solid body is compensated for by bringing the molecules of the gas closer together, as is done by compression, provided there is no change in the viscosity of the gas. The actual change in this, being small and known, can be taken into account. The new compressed air wind-tunnel therefore offers a means of learning in advance from experiments on models the characteristics of actual airplanes. It is needless to emphasize the practical importance of this possibility.

If opportunity permitted, I could mention a number of other investigations, purely scientific in their conception, which have an intensely practical interest to the industry. These few illustrations will suffice, however, to emphasize the intimate connection between pure science and industrial needs.

The Variation of the Dielectric Constants of Certain Liquids with Temperature. M. JEZEWSKI. (*Jour. de Phys. et le Radium,* Aug., 1922.)—In a primary circuit having self-induction and capacity electrical oscillations are set up. Loosely coupled to the first circuit is a second in which oscillations are induced, which have their maximum amplitude when a simple relation between the frequency of the primary oscillations and the inductance and capacity of the secondary circuit holds. A variable capacity here makes it possible to tune the secondary circuit to resonance with the first. After this has been accomplished a capacity having for dielectric the liquid under investigation is put in parallel with the variable condenser. This disturbs the resonance by reason of the increased capacity. To restore the former state the variable capacity must be decreased by an amount equal to the capacity of the liquid condenser. Thus is the

dielectric constant obtainable at various temperatures. To determine when the resonance is at its best, a third circuit is coupled to the second. In it is a crystal detector transmitting current to an Einthoven string galvanometer.

Aniline, nitrobenzene, glycerine and water were studied. In all the dielectric constant grew less as the temperature rose, and in all the decrease was very considerable. For aniline the constant at .25° C. was 7.418 and at 174.5°, 4.194. Nitrobenzene manifested the greatest change, 18.6°, 35.67; 203.9°, 15.37. Glycerine, 17°, 46.6; 144.5°, 28.7. Water, 2.3°, 90.7; 99.5°, 57.4. A formula proposed by Debye connecting density, temperature and dielectric constant is found to fit the facts well, but the values of certain numerical constants that must be supplied in the formula are in "flagrant disagreement" with Debye's theory.

It is surely a misnomer to call the specific inductive capacity a constant, when experiment shows that it is a variable. G. F. S.

The Effect of the Admixture of Small Quantities of Iron on the Susceptibility of Diamagnetic Elements. O. E. FRIVOLT. (*Ann. der Phys.*, Bd. 68, page 356.)—Since the susceptibility of iron is some millions of times as great as that of the diamagnetic elements, a very small quantity of the metal might well mask the magnetic properties of the latter. The purest silver obtainable from a firm of jewelers in Christiana was first investigated. For small magnetizing fields its susceptibility was found to be positive, but for fairly large values it became negative. Silver was then deposited electrolytically from a specimen of the metal already measured and the susceptibility of the element in the form of powder was determined. Change in field strength made little difference in the value of this quantity, nor was any change of sign produced. Next the powder was melted together in an electric furnace in an atmosphere of oxygen. This caused no considerable change in the susceptibility. Silver melted in air acted in the same manner. After deposition the susceptibility was in all cases negative. To the pure silver small quantities of iron were then added. When the iron content amounted to .028 per cent., the susceptibility was found to change from positive to negative with increasing field strengths, as was the case with the commercial metal. These experiments emphasize anew the necessity of having pure elements for magnetic investigations. G. F. S.

Panama Canal Business.—The *Commerce Monthly*, published by the National Bank of Commerce of New York City, states that the tonnage passing through the Canal during the third quarter of 1922 was 50 per cent. greater than that of the corresponding period of 1921, constituting a new high record. The tonnage increased steadily during 1919 and 1920, but fell off in the following year. During 1922, however, the business has steadily increased and reached amounts which fully set off the former decline. H. L.

ALTERNATING CURRENT CABLE TELEGRAPHY.*

BY

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THE use of alternating currents for cable telegraphy was first proposed by General George O. Squier some years ago. In his paper entitled "On an Unbroken Alternating Current for Cable Telegraphy" presented before The Physical Society of London in 1915,[1] he discussed at length the advantages of the alternating current method and described a scheme for the practical operation of the system. He proposed to use an unbroken alternating current continuously acting on the cable and effecting the signalling by varying the amplitudes of successive half cycles or multiples thereof in different degrees for dashes, dots and spaces. General Squier emphasized the advantages of the a. c. method on several occasions, pointing out that a better balance could be obtained on the duplex bridge, sharper definition of signals, and higher speed. Undoubtedly, the alternating current system offers many advantages, certainly in the matter of bridge balance it should prove to be superior to the battery spark system. The disturbances produced by a sudden break in the cable circuit, which is the method of signalling by the battery system, is the worst possible condition for the bridge balance. There are other differences in the two systems, alternating current *versus* direct current, which are of a more or less fundamental character and merit extensive study.

We have a considerable amount of theory and experimental data on the d. c. system of cable telegraphy, a number of investigators have contributed to the study of this problem, Doctor Heaviside's masterly discussion of the many problems connected with d. c. cable telegraphy will remain for a long time the classic work on this subject, he has covered almost every conceivable phase of the subject. For the a. c. system, however, we have very little experimental data, and practically no theory. The only discussion on the subject to my knowledge is the chapter on Sine

* Communicated by General George O. Squier, Chief Signal Officer, U.S.A., and Associate Editor of this JOURNAL.

[1] *Proceedings of the Physical Society of London*, Vol. 27, Part V, August 15, 1915.

Wave Transmission in the excellent book, "Theory of the Submarine Telegraph and Telephone Cable" by H. W. Malcolm. Unfortunately, the mathematical treatment of this section by Malcolm is defective and leads to erroneous conclusions, as will be pointed out further on.

In this paper I shall limit the discussion to a study of the so-called arrival curves for an impressed sinusoidal e.m.f. on a cable with and without terminal apparatus, and compare the results with those given by Doctor Malcolm in his book. It is, of course, very important that we should first of all establish a correct theory of the subject.

In a previous paper, "Electrical Oscillations on Lines," [2] I have considered the general problem of transient currents on a line, taking into consideration all the electrical constants of the line, *i.e.*, inductance, capacity, resistance and leakage, and have shown that by neglecting the inductance and the leakage, the solution applies to the ocean cable telegraph problem. To facilitate, however, the discussion of this specific problem, I shall give here briefly the derivation of the formulæ used in this paper. Designating by R and C the resistance and capacity of the cable and neglecting the inductance, we have the following circuit equations giving the voltage current relation for any element of the cable,

$$\left.\begin{aligned} RI &= -\frac{dV}{dx}, \\ CpV &= -\frac{dI}{dx}. \end{aligned}\right\} \tag{1}$$

p is the time differential operator, $p = \frac{d}{dt}$.

By substitution from the second equation into the first, we obtain the equation of propagation,

$$\frac{d^2V}{dx^2} = q^2V, \tag{2}$$

$$q^2 = RCp. \tag{3}$$

The solution of equation (2) is

$$V = A\varepsilon^{qx} + B\varepsilon^{-qx}. \tag{4}$$

By the aid of either equation of (1) we get the expression for the current at any point on the cable,

$$I = \frac{q}{R}\left\{-A\varepsilon^{qx} + B\varepsilon^{-qx}\right\}. \tag{5}$$

[2] JOURNAL OF THE FRANKLIN INSTITUTE, January, 1923, Vol. 195, No 1.

The constants A and B are to be determined by the terminal conditions. Consider first the simplest case that of a free cable, no terminal apparatus, an e.m.f. impressed at one end of the cable and grounded at the other end. The terminal conditions in this case are,

$$\left.\begin{array}{l} \text{for } x = o,\ V = E\varepsilon^{j\omega t}, \\ \text{for } x = l,\ V = o, \end{array}\right\} \tag{6}$$

assuming a sinusoidal e.m.f. impressed on the cable. Since the complex function $\varepsilon^{j\omega t}$ is used above in place of the Sine function, only the real part is to be used in the final results.

Substituting the values from (6) into (4), we get

$$\left.\begin{array}{l} A + B = E\varepsilon^{j\omega t}, \\ A\varepsilon^{ql} + B\varepsilon^{-ql} = o. \end{array}\right\} \tag{7}$$

The values of A and B are readily determined from the above two equations, as follows:

$$\left.\begin{array}{l} A = \dfrac{-E\varepsilon^{-ql}}{\varepsilon^{ql} - \varepsilon^{-ql}}\varepsilon^{j\omega t}, \\ B = \dfrac{E\varepsilon^{ql}}{\varepsilon^{ql} - \varepsilon^{-ql}}\varepsilon^{j\omega t}. \end{array}\right\} \tag{8}$$

Substituting these values in (4) and (5), we get the expressions for the voltage and current at any point on the cable,

$$\left.\begin{array}{rl} V = & \dfrac{E\{\varepsilon^{q(l-x)} - \varepsilon^{-q(l-x)}\}}{\varepsilon^{ql} - \varepsilon^{-ql}}\varepsilon^{j\omega t} \\ = & \dfrac{E\,\mathrm{Sinh}\,q(l-x)}{\mathrm{Sinh}\,ql}\varepsilon^{j\omega t}, \\ I = & \dfrac{q}{R}E\dfrac{\mathrm{Cosh}\,q(l-x)}{\mathrm{Sinh}\,ql}\varepsilon^{j\omega t}. \end{array}\right\} \tag{9}$$

In the above expressions q includes the time differential operator p which is so far indeterminate. Utilizing the method I have developed in my paper on "Electrical Oscillations on Lines," [3] we write,

$$\frac{ql}{\mathrm{Sinh}\,ql} = 1 - \frac{2}{1 + \left(\frac{\pi}{ql}\right)^2} + \frac{2}{1 + \left(\frac{2\pi}{ql}\right)^2} - \frac{2}{1 + \left(\frac{3\pi}{ql}\right)^3} + \cdots\cdots \tag{10}$$

Now consider first term of the above series,

$$\frac{1}{1 + \left(\frac{\pi}{ql}\right)^2} = \frac{1}{1 + \frac{\pi^2}{RCl^2p}} = \frac{1}{1 + \frac{m}{p}}, \quad \left(m = \frac{\pi^2}{RCl^2}\right) \tag{11}$$

[3] *Loc cit.*

expanding in a series, we have

$$\frac{1}{1+\frac{m}{p}} = 1 - \frac{m}{p} + \frac{m^2}{p^2} - \frac{m^3}{p^3} + \cdots\cdots \tag{12}$$

Operating by this series on $\varepsilon^{\gamma t}$, replacing $j\omega$ by γ for simplicity, we get

$$\begin{aligned}
&\frac{1}{p}\varepsilon^{\gamma t} = \int_0^t \varepsilon^{\gamma t} dt = \frac{1}{\gamma}\varepsilon^{\gamma t} - \frac{1}{\gamma} \\
&\frac{1}{p^2}\varepsilon^{\gamma t} = \int_c^t \int_0^t \varepsilon^{\gamma t} dt = \frac{1}{\gamma^2}\varepsilon^{\gamma t} - \frac{1}{\gamma^2} - \frac{1}{\gamma} t \qquad (13) \\
&\frac{1}{p^3}\varepsilon^{\gamma t} = \qquad\qquad = \frac{1}{\gamma^3}\varepsilon^{\gamma t} - \frac{1}{\gamma^3} - \frac{1}{\gamma^2} t - \frac{1}{\gamma}\frac{t^2}{\underline{|2}} \\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
&\frac{1}{p^m}\varepsilon^{\gamma} - \frac{1}{\gamma^m}\varepsilon^{\gamma t} - \frac{1}{\gamma^m} - \frac{1}{\gamma^{m-1}} t - \frac{1}{\gamma^{m-2}}\frac{t^2}{\underline{|2}} - \frac{1}{\gamma^{m-3}}\frac{t^3}{\underline{|3}} - \frac{1}{\gamma^{m-4}}\frac{t^4}{\underline{|4}} - \cdots\cdots
\end{aligned}$$

Substituting from (13) in (12) and rearranging, we have

$$\begin{aligned}
\frac{1}{1+\frac{m}{p}}\varepsilon^{\gamma t} &= \varepsilon^{\gamma t}\left(1 - \frac{m}{\gamma} + \frac{m^2}{\gamma^2} - \frac{m^3}{\gamma^3} + \cdots\cdots\right) \\
&\quad + \frac{m}{\gamma}\left(1 - \frac{m}{\gamma} + \frac{m^2}{\gamma^2} - \frac{m^3}{\gamma^3} + \cdots\cdots\right) \\
&\quad - \frac{m}{\gamma} mt\left(1 - \frac{m}{\gamma} + \frac{m^2}{\gamma^2} - \frac{m^3}{\gamma^3} + \cdots\cdots\right) \\
&\quad + \frac{m}{\gamma}\frac{m^2t^2}{\underline{|2}}\left(1 - \frac{m}{\gamma} + \frac{m^3}{\gamma^2} - \frac{m^3}{\gamma^3} + \cdots\cdots\right) \\
&\quad - \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
&= \frac{1}{1+\frac{m}{\gamma}}\varepsilon^{\gamma t} + \frac{m}{\gamma}\frac{1}{1+\frac{m}{\gamma}}\left(1 - mt + \frac{m^2t^2}{\underline{|2}} - \frac{m^3t^3}{\underline{|3}} + \cdots\cdots\right) \\
&= \frac{1}{1+\frac{m}{\gamma}}\left\{\varepsilon^{\gamma t} + \frac{m}{\gamma}\varepsilon^{-mt}\right\}. \qquad (14)
\end{aligned}$$

Operating in the same way on $\varepsilon^{\gamma t}$ by the other terms of the series (10) and collecting the results, we get

$$\begin{aligned}
\frac{ql}{\operatorname{Sinh} ql}\varepsilon^{\gamma t} = \varepsilon^{\gamma t} &- \frac{2\left(\varepsilon^{\gamma t} + \frac{m}{\gamma}\varepsilon^{-mt}\right)}{1+\frac{m}{\gamma}} + \frac{2\left(\varepsilon^{\gamma t} + \frac{4m}{\gamma}\varepsilon^{-4mt}\right)}{1+\frac{4m}{\gamma}} \\
&- \frac{2\left(\varepsilon^{\gamma t} - \frac{9m}{\gamma}\varepsilon^{-9mt}\right)}{1+\frac{9m}{\gamma}} + \cdots\cdots \qquad (15)
\end{aligned}$$

We may write equation (15) in the following form:

$$\frac{ql}{\operatorname{Sinh} ql}\varepsilon^{\gamma t} = \varepsilon^{\gamma t}\left\{1 - \frac{2}{1+\frac{m}{\gamma}} + \frac{2}{1+\frac{4m}{\gamma}} - \frac{2}{1+\frac{9m}{\gamma}} + \cdots\right\}$$

$$- \frac{2m}{\gamma}\left\{\frac{\varepsilon^{-mt}}{1+\frac{m}{\gamma}} - \frac{4\varepsilon^{-4mt}}{1+\frac{4m}{\gamma}} + \frac{9\varepsilon^{-9mt}}{1+\frac{9m}{\gamma}} - \cdots\right\} \qquad (16)$$

By inspection it is seen that the series of the first bracket in (16) is of the same form as the series (10), except that $\frac{\pi^2}{q^2l^2}$ is replaced by $\frac{m}{\gamma}$, the sum of the series is therefore equal to

$$\frac{\pi\sqrt{\frac{\gamma}{m}}}{\operatorname{Sinh}\pi\sqrt{\frac{\gamma}{m}}}.$$

Hence

$$\frac{ql}{\operatorname{Sinh} ql}\varepsilon^{\gamma t} = \frac{\pi\sqrt{\frac{\gamma}{m}}}{\operatorname{Sinh}\pi\sqrt{\frac{\gamma}{m}}}\varepsilon^{\gamma t} + \frac{2m}{\gamma}\sum_{1}^{\infty}\frac{(-1)^n n^2\varepsilon^{-n^2mt}}{1+\frac{n^2m}{\gamma}}. \qquad (17)$$

To get the expression for the voltage on the cable the above is to be operated on by $\frac{E\operatorname{Sinh} q(l-x)}{ql}$. The series of this factor involves only even powers of q and therefore integral powers of p, thus

$$\frac{\operatorname{Sinh} q(l-x)}{ql} = \frac{q(l-x) + \frac{q^3(l-x)^3}{\lfloor 3} + \frac{q^5(l-x)^5}{\lfloor 5} + \cdots}{ql}$$

$$= \left(1-\frac{x}{l}\right) + \frac{q^2l^2\left(1-\frac{x}{l}\right)^3}{\lfloor 3} + \frac{q^4l^4\left(1-\frac{x}{l}\right)^5}{\lfloor 5} + \cdots \qquad (18)$$

and operating by the above on (17) involves only time differentiation. Operating on the first term of (17), we have

$$q^2l^2\varepsilon^{\gamma t} = RCl^2p\varepsilon^{\gamma t} = RCl^2\gamma\varepsilon^{\gamma t} = \frac{\pi^2\gamma}{m}\varepsilon^{\gamma t},$$

$$q^4l^4\varepsilon^{\gamma t} = R^2C^2l^4p^2\varepsilon^{\gamma t} = R^2C^2l^4\gamma^2\varepsilon^{\gamma t} = \frac{\pi^4\gamma^2}{m^2}\varepsilon^{\gamma t},$$

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hence

$$\frac{\operatorname{Sinh} q(l-x)}{ql}\varepsilon^{\gamma t} = \frac{\operatorname{Sinh}\pi\sqrt{\frac{\gamma}{m}}\left(1-\frac{x}{l}\right)}{\pi\sqrt{\frac{\gamma}{m}}}\varepsilon^{\gamma t}. \qquad (19)$$

Similarly operating by (18) on the summation term of (17),

$$q^2l^2\varepsilon^{-n^2ml} = RCl^2p\varepsilon^{-n^2ml} = -RCl^2n^2m\varepsilon^{-n^2ml} = -\pi^2n^2\varepsilon^{-n^2ml},$$

$$q^4l^4\varepsilon^{-n^2ml} = R^2C^2l^4p^2\varepsilon^{-n^2ml} = R^2C^2l^4n^4m^2\varepsilon^{-n^2ml} = \pi^4n^4\varepsilon^{-n^2ml}.$$

. . . . . .

For all the terms in the series (18),

$$\frac{\operatorname{Sinh} q(l-x)}{ql}\varepsilon^{-n^2ml}$$

$$= \left\{\left(1-\frac{x}{l}\right) - \frac{\pi^2n^2\left(1-\frac{x}{l}\right)^3}{\lfloor 3} + \frac{\pi^4n^4\left(1-\frac{x}{l}\right)^5}{\lfloor 5} - \cdots\right\}\varepsilon^{-n^2ml}$$

$$= \left(1-\frac{x}{l}\right)\left\{1 - \frac{n^2\pi^2}{\lfloor 3}\left(1-\frac{x}{l}\right)^2 + \frac{n^4\pi^4}{\lfloor 5}\left(1-\frac{x}{l}\right)^4 - \cdots\right\}\varepsilon^{-n^2ml}$$

$$= \left(1-\frac{x}{l}\right)\frac{\operatorname{Sin} n\pi\left(1-\frac{x}{l}\right)}{n\pi\left(1-\frac{x}{l}\right)}\varepsilon^{-n^2ml} = \frac{\operatorname{Sin} n\pi\left(1-\frac{x}{l}\right)}{n\pi}\varepsilon^{-n^2ml}. \quad (20)$$

Substituting the values from (19) and (20) in (17), we get the following expression for the voltage on the cable:

$$V = \frac{E\operatorname{Sinh}\pi\sqrt{\frac{\gamma}{m}}\left(1-\frac{x}{l}\right)}{\operatorname{Sinh}\pi\sqrt{\frac{\gamma}{m}}}\varepsilon^{\gamma t} + 2E\frac{m}{\gamma}\sum_1^\infty(-1)^n\frac{n^2\operatorname{Sin} n\pi\left(1-\frac{x}{l}\right)}{n\pi\left(1+\frac{n^2m}{\gamma}\right)}\varepsilon^{-n^2ml}. \quad (21)$$

Replacing m by its equivalent $\frac{\pi^2}{RCl^2}$ and γ by $j\omega$ and simplifying, we obtain

$$V = \frac{E\operatorname{Sinh}\sqrt{j\omega RC}\,(l-x)}{\operatorname{Sinh}\sqrt{j\omega RC}\,l}\varepsilon^{j\omega t} + 2E\sum_1^\infty(-1)^n\frac{n\pi\operatorname{Sin} n\pi\left(1-\frac{x}{l}\right)}{j\omega RCl^2+n^2\pi^2}\varepsilon^{-\frac{n^2\pi^2}{RCl^2}t}. \quad (22)$$

The expression for the current on the cable is readily obtained from (22) by the relation

$$I = -\frac{1}{R}\frac{dV}{dx}$$

$$I = \frac{E\sqrt{j\omega RC}}{R}\frac{\operatorname{Cosh}\sqrt{j\omega RC}\,(l-x)}{\operatorname{Sinh}\sqrt{j\omega RC}\,l}\varepsilon^{j\omega t} + \frac{2E}{Rl}\sum_1^\infty(-1)^n\frac{n^2\pi^2\operatorname{Cos} n\pi\left(1-\frac{x}{l}\right)}{j\omega RCl^2+n^2\pi^2}\varepsilon^{-\frac{n^2\pi^2}{RCl^2}t} \quad (23)$$

The real parts of above equations (22) and (23) are the complete expressions for the voltage and current distributions on the cable. The first terms of the right-hand side of equations (22) and (23) give the steady state, periodic component of voltage

and current and the other terms the transient voltage and current. We may put for convenience

$$\left.\begin{aligned} V &= V_s + V_t \\ V_s &= \frac{E \operatorname{Sinh} \sqrt{j\omega RC}\,(l-x)}{\operatorname{Sinh} \sqrt{j\omega RC}\,l}\,\varepsilon^{j\omega t}, \\ V_t &= 2E \sum_1^\infty (-1)^n \frac{n\pi \operatorname{Sin} n\pi\left(1-\frac{x}{l}\right)}{j\omega RCl^2 + \pi^2 n^2}\,\varepsilon^{-\frac{n^2\pi^2}{RCl^2}t}. \end{aligned}\right\} \quad (24)$$

$$\left.\begin{aligned} I &= I_s + I_t, \\ I_s &= \frac{E\sqrt{\frac{j\omega C}{R}} \operatorname{Cosh} \sqrt{j\omega RC}\,(l-x)}{\operatorname{Sinh} \sqrt{j\omega RC}\,l}\,\varepsilon^{j\omega t}, \\ I_t &= \frac{2E}{Rl} \sum_1^\infty (-1)^n \frac{n^2\pi^2 \operatorname{Cos} n\pi\left(1-\frac{x}{l}\right)}{j\omega RCl^2 + n^2\pi^2}\,\varepsilon^{-\frac{n^2\pi^2}{RCl^2}t}. \end{aligned}\right\} \quad (25)$$

For the current at the receiving end of the cable, $x = l$, the above reduce to

$$\left.\begin{aligned} I_s &= \frac{E\sqrt{\frac{j\omega C}{R}}}{\operatorname{Sinh} \sqrt{j\omega RC}\,l}\,\varepsilon^{j\omega t}, \\ I_t &= \frac{2E}{Rl} \sum_1^\infty (-1)^n \frac{n^2\pi^2}{j\omega RCl^2 + \pi^2 n^2}\,\varepsilon^{-\frac{n^2\pi^2}{RCl^2}t}. \end{aligned}\right\} \quad (26)$$

The formula for I_t given by (26) agrees with the one obtained by Malcolm by a different method, and given in his book equation (9), page 363. Malcolm made the error, however, in taking the imaginary part of the equation for calculating the received current instead of the real part as he should have done. This, of course, vitiates all his numerical calculations. In his discussion of "The Influence of Terminal Apparatus," Sine Wave Transmission, he made a more fundamental error in theory as will be shown further on. Taking the real parts of (26), we get for the received current,

$$\left.\begin{aligned} I_s &= \frac{E\sqrt{\frac{\omega C}{R}} \operatorname{Cos}\left(\omega t - \sqrt{\frac{RC\omega}{2}}\,l + \frac{\pi}{4}\right)}{\operatorname{Sinh} \sqrt{\frac{RC\omega}{2}}\,l}, \\ I_t &= \frac{2E}{Rl} \sum_1^\infty (-1)^n \frac{n^4\pi^4}{\omega^2 R^2 C^2 l^4 + n^4\pi^4}\,\varepsilon^{-\frac{n^2\pi^2 t}{RCl^2}}. \end{aligned}\right\} \quad (27)$$

Putting $\omega = o$ equations (22) and (23) reduce to

$$\left.\begin{aligned} V = V_s + V_t &= E\left(1 - \frac{x}{l}\right) + 2E\sum_1^\infty (-1)^n \frac{\operatorname{Sin} n\pi\left(1 - \frac{x}{l}\right)}{n\pi} \varepsilon^{-\frac{n^2\pi^2}{RCl^2}t}, \\ I = I_s + I_t &= \frac{E}{Rl} + \frac{2E}{Rl}\sum_1^\infty (-1)^n \operatorname{Cos} n\pi\left(1 - \frac{x}{l}\right) \varepsilon^{-\frac{n^2\pi^2}{RCl^2}t}. \end{aligned}\right\} \quad (28)$$

which are the well-known expressions for the voltage and current distribution on a cable for constant e.m.f. For $x = l$ and $\omega = o$ the second equation of (28) reduces to

$$I = \frac{E}{Rl} + \frac{2E}{Rl}\sum_1^\infty (-1)^n \varepsilon^{-\frac{n^2\pi^2}{RCl^2}t}. \quad (29)$$

To calculate the transient component of the received current the second equation of (27) is to be used. By taking the imaginary part of (26) Malcolm arrives at the following expression for the transient component of the received current:

$$I = \frac{2E}{Rl}\sum_1^\infty \frac{\varepsilon^{-\frac{n^2\pi^2}{RCl^2}t} \operatorname{Cos}(m-1)\pi}{\frac{\omega RCl^2}{n^2\pi^2} + \frac{n^2\pi^2}{\omega RCl^2}}. \quad (30)$$

(See Malcolm, page 363, equation 11.)

It is quite obvious that this expression is wrong, putting $\omega = o$ leads to the result $I_t = o$.

The difference in the results obtained in any practical case by the use of formula (27), which is the correct formula and Malcolm's formula (30), is very marked. For the purpose of comparison I will use the same cable data that Malcolm used in his calculations. He took the data of the San Francisco-Honolulu section of the Commercial Cable Company,

$l = 2{,}276.4$ n. ms.
$R = 2.1856$ ohms per n. m.
$C = 0.3842$ mfds. per n. m.
$Rl = 4975$ ohms.
$Cl = 874.6$ mfds.
$RCl^2 = 4.3514$ secs.

Assume a frequency of 10 cycles per second,

$$\omega = 2\pi \times 10 = 62.832, \quad \omega^2 R^2 C^2 l^4 = 74{,}753.$$

Applying these numerical values to formula (27) and calculating for values of n from 1 to 6, we get the following tables:

TABLE I.

n	$n^4\pi^4$	$\frac{n^4\pi^4}{n^4\pi^4+\omega^2R^2C^2l^4}$
1	97.417	0.00132
2	1,558.67	0.0204
3	7,890.78	0.0955
4	24,938.75	0.2501
5	60,985.6	0.4487
6	126,252	0.6281

The values of $\frac{2}{Rl}\varepsilon^{-\frac{n^2\pi^2}{RCl^2}t}$ for this particular cable were calculated by Malcolm and given in his book, Table 58, page 302, which is reproduced here, the values given in the table are in microamperes per volt.

TABLE II.

t (secs.)	0.1	0.2	0.3	0.4	0.5	0.7	1.0	1.5	2	3
$n=1$	320.4	255.4	203.6	162.3	129.3	82.2	41.6	13.4	4.3	0.5
$n=2$	162.3	65.5	26.4	10.7	4.3	0.7	0.1	....	...	...
$n=3$	52.2	6.8	0.9	0.1	.....	....	....	....	...	...
$n=4$	10.7	0.3	.....	.....	.....	....	....	....	...	...
$n=5$	1.4	.....	.....	.....	.....	....	....	....	...	...
$n=6$	0.1	.....	.....	.....	.....	....	....	....	...	...

Multiplying each of the values of Table II by the values given in the last column of Table I and taking account of the factor $(-1)^n$ in formula (27) the values given in Table III are calculated from which the received current at different times after the application of the e.m.f. is calculated and given in the last line.

By Malcolm's formula given in his book on page 365, Table 82, the corresponding values are as follows:

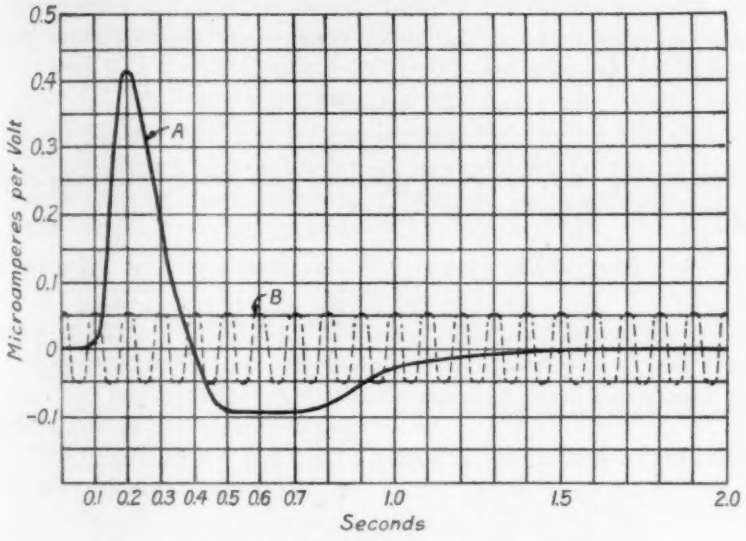
t(secs).	0.1	0.2	0.3	0.4	0.5	0.7	1.0	1.5	2	3
I_r	−0.045	+1.814	+3.852	+4.371	+4.055	+2.862	+1.493	+0.483	+0.155	+0.016

The difference in the results obtained by the two formulæ is shown graphically by the curves of Figs. 1 and 2. The periodic component of the received current is the same in both cases, the amplitude is 0.057 microampere per volt.

TABLE III.

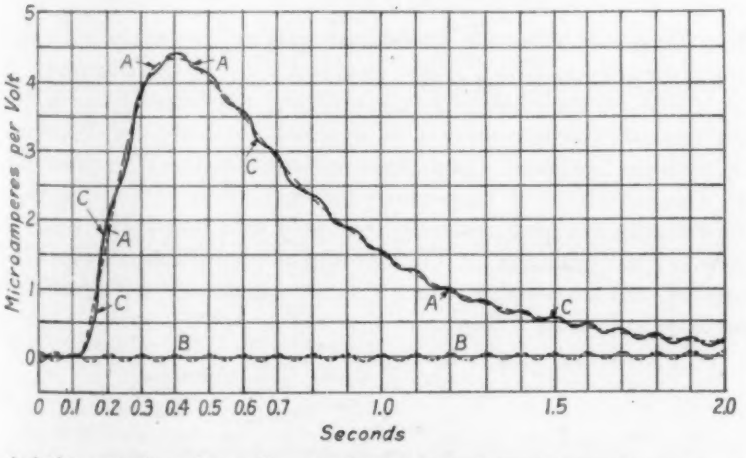
t(secs.)	0.1	0.2	0.3	0.4	0.5	0.7	1.0	1.5	2.0	3.0
$n=1$	−0.4230	0.3371	0.2687	0.2140	0.1706	0.1085	0.0549	0.0177	0.0057	0.00066
$n=2$	+3.3109	1.3362	0.5386	0.2183	0.0877	0.0143	0.0020	.....	.....	.....
$n=3$	−4.9851	0.6494	0.0860	0.0075	.....	.....	.....	.....	.....	.....
$n=4$	+2.6761	0.0750	.....	.....	.....	.....	.....	.....	.....	.....
$n=5$	−0.6282	.....	.....	.....	.....	.....	.....	.....	.....	.....
$n=6$	+0.0628	.....	.....	.....	.....	.....	.....	.....	.....	.....
Received Current, I_r	+0.0135	+0.4247	+0.1839	−0.0052	−0.083	−0.0942	− 0.035	−0.0117	−0.0057	−0.00066

FIG. 1.



Arrival current, alternating e.m.f. $n=10$. Curve A–transient component. Curve B (broken)–periodic component.

FIG. 2.



Arrival current, alternating e.m.f. $n=10$. Curve A (broken)–transient component. Curve B (broken)–periodic component. C=total current. C=A+B.

THE INFLUENCE OF TERMINAL APPARATUS.

Assume impedances Z_t and Z_r connected at the transmitting and receiving ends of the cable, respectively; the terminal conditions in this case are

$$\left.\begin{array}{l} \text{for } x = o,\ V = E\varepsilon^{j\omega t} - Z_t I_o\ , \\ \text{“ } x = l,\ V = Z_r I_l\ . \end{array}\right\} \tag{31}$$

Substituting these values in equations (4) and (5) the constants A and B are determined as follows:

$$\left.\begin{array}{l} A = \dfrac{E\left(1 - \dfrac{Z_r q}{R}\right)\varepsilon^{-ql}}{\left(1 + \dfrac{Z_t Z_r}{R^2} q^2\right)\left(\varepsilon^{-ql} - \varepsilon^{ql}\right) - \dfrac{q}{R}\left(Z_t + Z_r\right)\left(\varepsilon^{ql} + \varepsilon^{-ql}\right)}\ , \\ B = \dfrac{-E\left(1 + \dfrac{Z_r}{R} q\right)\varepsilon^{ql}}{\text{Same denominator}} \end{array}\right\} \tag{32}$$

and

$$I = \frac{E\frac{q}{R}\left\{\left(1 - \frac{Z_r q}{R}\right)\varepsilon^{-q(l-x)} + \left(1 + \frac{Z_r q}{R}\right)\varepsilon^{q(l-x)}\right\}\varepsilon^{j\omega t}}{\left(1 + \frac{Z_r Z_t}{R^2} q^2\right)\left(\varepsilon^{ql} - \varepsilon^{-ql}\right) + \frac{q}{R}\left(Z_t + Z_r\right)\left(\varepsilon^{ql} + \varepsilon^{-ql}\right)}\ . \tag{33}$$

For $x = l$ the received current is given by

$$I_r = \frac{E\varepsilon^{j\omega t}}{\left(\frac{R}{q} + Z_r Z_t \frac{q}{R}\right)\operatorname{Sinh} ql + \left(Z_t + Z_r\right)\operatorname{Cosh} ql}\ . \tag{34}$$

For the steady state, the periodic component, replacing p by $j\omega$ in the q expression ($q = \sqrt{RCp}$), equation (34) is the solution. To get the complete solution to the problem, the transient as well as the periodic components, it is simplest to apply the Heaviside Expansion Theorem. In a paper published in the December issue of this JOURNAL [4] I have given the derivation of the Heaviside Expansion Theorem, extended to apply to a sinusoidal e.m.f. as well as a constant e.m.f. The theorem as formulated by Heaviside applies only to constant e.m.f. The formula derived from sinusoidal e.m.f. is as follows:

$$I = \frac{E\varepsilon^{j\omega t}}{Z(p)_{\,p = j\omega}} - \sum_{p_1}^{p_n} \frac{\varepsilon^{p_n t}}{(j\omega - p_n)\dfrac{\partial Z(p)}{\partial p}_{\,p = p_n}}\ . \tag{35}$$

[4] “The Heaviside Expansion Theorem,” JOURNAL FRANKLIN INSTITUTE, Dec., 1922.

The first term of the right-hand side of the above equation gives the periodic component of the current and the summation term the transient component. The summation is to be extended to all the roots of the determinental equation,

$$Z(p) = 0. \tag{36}$$

Doctor Malcolm utilizes the same method in getting the solution to this problem, but he made the serious error in applying the expansion formula as given by Heaviside for a constant e.m.f. to the condition of sinusoidal e.m.f. He modified the formula arbitrarily by the factor $\frac{1}{\frac{\omega CRl^2}{p^2} + \frac{p^2}{\omega CRl^2}}$ for which there does not seem to be any foundation in theory. His conclusions therefore in this case are of course wrong. The difference in the final results in any practical case will be shown by the following consideration of one special case.

Take the case worked out by Malcolm, condensers of the same size at each end of the cable,

$$Z_t = Z_r = \frac{1}{C_0 p}.$$

Substituting in (34)

$$I_r = \frac{E\varepsilon^{j\omega t}}{\left(\frac{R}{q} + \frac{q}{RC_0^2p^2}\right)\operatorname{Sinh} ql + \frac{2}{C_0p}\operatorname{Cosh} ql} \tag{37}$$

The determinental equation for this case is

$$Z(p) = \left(\frac{R}{q} + \frac{q}{RC_0^2p^2}\right)\operatorname{Sinh} ql + \frac{2}{C_0p}\operatorname{Cosh} ql = 0 \tag{38}$$

Remembering that $q = \sqrt{RCp}$, we have on differentiating with respect to p

$$\begin{aligned}\frac{\partial Z(p)}{\partial p} = {} & \left(\frac{R}{\sqrt{RCp}} + \frac{\sqrt{RCp}}{RC_0^2p^2}\right)\frac{\sqrt{RC}l}{2\sqrt{p}}\operatorname{Cosh}\sqrt{RCp}l - \frac{1}{2\sqrt{p}}\left\{\frac{R}{\sqrt{RCp}} + \frac{3\sqrt{RC}}{RC_0^2p^2}\right\}\cdot \\ & \cdot\operatorname{Sinh}\sqrt{RCp}l + \frac{1}{C_0p}\frac{\sqrt{RC}l}{\sqrt{p}}\operatorname{Sinh}\sqrt{RCp}l - \frac{2}{C_0p^2}\operatorname{Cosh}\sqrt{RCp}l \\ = {} & \frac{1}{2p}\left\{Rl + \frac{Cl}{C_0^2p} - \frac{4}{C_0p}\right\}\operatorname{Cosh}\sqrt{RCp}l \\ & - \frac{1}{2p\sqrt{p}}\left\{\frac{R}{\sqrt{RC}} + \frac{3\sqrt{RC}}{RC_0^2p} - \frac{2\sqrt{RC}l}{C_0}\right\}\operatorname{Sinh}\sqrt{RCp}l.\end{aligned} \tag{39}$$

By (38) we have

$$\operatorname{Cosh}\sqrt{RCp}l = -\frac{C_0p}{2}\left(\frac{R}{\sqrt{RCp}} + \frac{\sqrt{RCp}}{RC_0^2p^2}\right)\operatorname{Sinh}\sqrt{RCp}l,$$

substituting in (39), combining and rearranging,

$$\frac{\partial Z(p)}{\partial p} = \frac{1}{\sqrt{RCpl}} \left\{ -\frac{C_0 R^2 l^2}{4} + \frac{1}{2}\frac{Rl}{p} - \frac{C^2 l^2}{4C_0^2 p^2} - \frac{1}{2}\frac{Cl}{C_0^2 p^2} + \frac{1}{2}\frac{RCl}{C_0 p} \right\} \text{Sinh } \sqrt{RCpl}. \tag{40}$$

The value of $\frac{\partial Z(p)}{\partial p}$ given by above equation to be used in (35), assigning to p the values determined by (38).

As a practical illustration assume $C_0 = \frac{1}{10} Cl$, equation (40) reduces to

$$\frac{\partial Z(p)}{\partial p} = \frac{-Cl}{\sqrt{RCpl}} \left\{ \frac{R^2 l^2}{40} + \frac{300}{C^2 l^2 p^2} - \frac{5.5}{Clp} \right\} \text{Sinh } \sqrt{RCpl}. \tag{41}$$

To determine the roots of equation (38), we have

$$\tanh ql = \frac{-2}{C_0 p \left(\frac{R}{q} + \frac{q}{RC_0^2 p^2} \right)}, \tag{42}$$

put $ql = jx$, $RCpl^2 = -x^2$ and $p = \frac{-x^2}{RCl^2}$,

equation (42) reduces to

$$\tan x = \frac{2Cl}{C_0 \left(x - \frac{C^2 l^2}{C_0^2 x} \right)},$$

and for

$$C_0 = \frac{1}{10} Cl$$

$$\tan x = \frac{20}{x - \frac{100}{x}} \cdot \cdot \tag{43}$$

The first eight roots of the above equation and the corresponding values of p are as follows:

x 2.6272, 5.307, 8.067, 10.909, 13.819, 16.782, 19.786, 22.817
p −1.586 , −6.462, −14.951, −27.345, −43.88 , −60.14 , −87.67 , −119.65

By (35) we have for the transient component received current

$$I_t = \sum_{p_1}^{p_m} \frac{\mathcal{E} e^{p_n t}}{(j\omega - p_n) \frac{\partial Z(p)}{\partial p}} \quad p = p_n$$

The real part of above equations is

$$I_t = -\sum_{p_1}^{p_m} \frac{p \mathcal{E} e^{p_n t}}{(\omega^2 + p_n^2) \frac{\partial Z(p)}{\partial p}} \quad p = p_n$$

For the values of p, the roots of equation (38) given above, the following table was calculated.

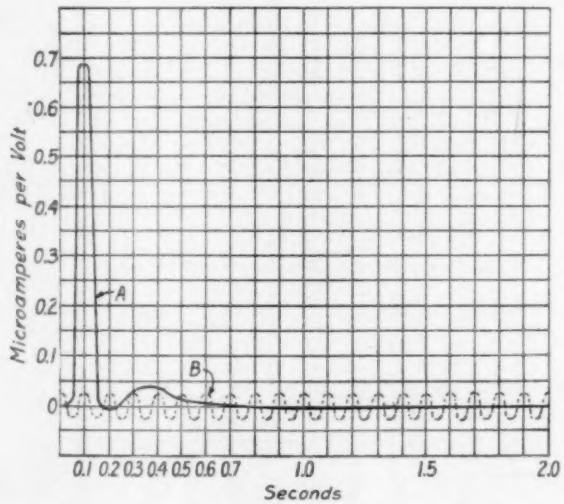
TABLE IV.

p	$\frac{p}{\omega^2+p^2}$	$\frac{\partial z(p)}{\partial p}$	$\frac{p}{(\omega^2+p^2)\frac{\partial z(p)}{\partial p}}$
−1.586	−0.0004	+28285	$-0.0141_{\times 10^{-6}}$
−6.472	−0.00162	−2022	$+0.801_{\times 10^{-6}}$
−14.951	−0.00358	+473	$-7.568_{\times 10^{-6}}$
−27.345	−0.00582	−140.7	$+41.364_{\times 10^{-6}}$
−43.88	−0.00747	+92.3	$-80.93_{\times 10^{-6}}$
−60.14	−0.00795	−61.2	$+129.9_{\times 10^{-6}}$
−87.67	−0.00753	+29.61	$-254.4_{\times 10^{-6}}$
−119.65	−0.00655	−18.24	$+359.0_{\times 10^{-6}}$

The values of ε^{pt} for different time intervals are tabulated below in Table V.

Multiplying the values given in Table V by the values given in last column of Table IV, Table VI is constructed in which the

FIG. 3.



Arrival current, alternating e.m.f. $n=10$. Curve A–transient component. Curve B(broken)–periodic component.

values of the transient current component are given. The values are in microamperes per volt.

The steady current component can be readily calculated by formula (37) replacing p by $j\omega$ and taking the real part thereof.

TABLE V.

t(secs.)	0.1	0.2	0.3	0.4	0.5	0.7	1.0	1.5	2	3
$p = -1.586$	0.8533	0.7282	0.6214	0.5303	0.4525	0.3295	0.2047	0.0926	0.0419	0.00857
$p = -6.472$	0.5235	0.2741	0.1435	0.0751	0.0393	0.01078	0.00155	$0.61_{\times 10^{-4}}$	.....	.....
$p = -14.951$	0.2242	0.0503	0.01127	0.00253	$0.569_{\times 10^{-3}}$	$0.285_{\times 10^{-4}}$	.....	.....	.....	.....
$p = -27.345$	0.0649	0.0042	$0.273_{\times 10^{-3}}$	$0.176_{\times 10^{-4}}$	$0.114_{\times 10^{-5}}$	.....	.....	.....	.....	.....
$p = -43.88$	0.0124	0.000154	$0.191_{\times 10^{-5}}$	.....	.....	.....	.....	.....	.....	.....
$p = -60.14$	0.0025	.....	.....	.....	.....	.....	.....	.....	.....	.....
$p = -87.67$	0.00156	.....	.....	.....	.....	.....	.....	.....	.....	.....
$p = -119.65$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE VI.

t(secs.)	0.1	0.15	0.2	0.3	0.4	0.5	0.7	1.0	1.5	2.0	3.0
$p = -1.586$	−0.0120	0.0111	0.0103	0.00876	0.00748	0.0064	0.00465	0.00289	0.00130	0.0006	0.00012
$p = -6.472$	+0.419	0.3036	0.220	0.1149	0.0602	0.0315	0.00863	0.00124	0.00005	.....	.....
$p = -14.951$	−1.697	0.8037	0.381	0.0853	0.0191	0.0043	0.00021	.....	.....	.....	.....
$p = -27.345$	+2.684	0.6825	0.174	0.0113	0.0007	0.00004	.....	.....	.....	.....	.....
$p = -43.88$	−1.003	0.1117	0.0125	0.00015	.....	.....	.....	.....	.....	.....	.....
$p = -60.14$	+0.325	0.0156	0.0008	.....	.....	.....	.....	.....	.....	.....	.....
$p = -87.67$	−0.0396	0.0742	.....	.....	.....	.....	.....	.....	.....	.....	.....
Received Current, I_r	+0.676	−0.0010	−0.0090	+0.032	+0.0443	+0.0208	+0.00377	−0.00165	−0.00125	−0.0006	−0.0001
Malcolm's values same example	−0.021	+0.189	+0.421	+0.435	+0.213	+0.039	−0.099	−0.101	−0.051	−0.023	−0.005

For a frequency of ten cycles per second the amplitude of the periodic component of the current thus calculated is 0.025 micro-ampere per volt.

The calculated values given in Table VI are shown in graphical form by the curves of Fig. 3.

The discussion in this paper was limited to a consideration of fundamental principles; it is highly important of course that we should have first of all a correct theory of the subject. The application of the theory developed here to some special problems in cable telegraphy, will be considered in another paper. I have in mind particularly the problem of signalling either by the method of resistance variation proposed by General Squier or the method of varying the length of cable cutting in or out sections of artificial cable proposed by the writer.[5] It is believed that these methods offer particular advantages in the alternating current system of cable telegraphy.

The Use of a Triode Valve in Registering Electrical Contacts. G. A. TOMLINSON. (*Phil. Mag.*, Nov., 1922.)—"A three-electrode valve can be applied with advantage to certain forms of apparatus in which use is made of electrical contacts. A common case is that of a relay in which it is usual to cause a feeble movement of one instrument to make a contact and close the circuit of a second comparatively powerful instrument supplied from an independent source. An improvement in several respects can be made if the first contact is placed in the grid circuit of a valve, and the second instrument is connected in the anode circuit and is operated by the anode current." For a relay of this type several advantages are claimed. The current through the contact points is small, being merely the grid current. Resistance at the points need not be always the same because there is in circuit the large resistance from grid to filament. "A further advantage, that may be important in some cases, is that this relay may be operated by much weaker forces than could be used with an ordinary relay. . . . It has been found that a contact force of 0.000001 grm. is quite sufficient to charge the grid and produce the required change in the anode current." In making exact measurements of thicknesses or distances electrical means are often used to determine the fact of contact. When the triode valve was employed for this purpose "it was found that repetition of observations could easily be obtained with variations not exceeding 0.5^{-6} inch." It is suggested that the method may be used for the reception of very feeble wireless signals. G. F. S.

[5] U. S. Patent No. 1,414,179, April 25, 1922.

A SURVEY OF EXISTING CRYSTAL STRUCTURE DATA.*

BY

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INTRODUCTION.

THE use of information furnished by the theory of space-groups in studying the arrangement of atoms in crystals has made possible a completely new attitude towards crystal structure results. Hitherto it was necessary to be content with the determination of a possible structure which would account for a few limited data taken in a haphazard fashion. Space-group results permit the detailed consideration of all of the atomic arrangements possible for a crystal and offer the opportunity of choosing the experimental data in such a manner that they will select the correct structure.

The results thus obtained are of a different order of value from those derived by the older procedure: In the one case a structure is achieved which may be the correct one; in the other, either a unique solution is deduced or else the several structures which remain possibilities are each of them completely known. In the earlier days any information concerning the internal construction of crystals was very properly treasured but now, when it is not necessary to be content with results of an uncertain character, there hardly remains the same justification for their accumulation.

Since there is such great difference between the worth of studies of crystal structure carried out by these two different procedures and since most of the work that has been and still is being done proceeds from the older point of view, a survey of existing crystal structure data is urgently needed. This paper aims in part to provide such a discussion. Most of the older determinations have not been checked up as yet. Many of them are of very simple crystals with a large probability of correctness. In judging the value of these studies, then, the element of personal

* Communicated by Dr. Arthur L. Day, Director of the Geophysical Laboratory and Associate Editor of this JOURNAL.

judgment must necessarily be introduced, and allowed for, though it distinctly is not involved in comparative discussions of work carried out by the older and newer methods. Eventually all of the old determinations must be more or less thoroughly reworked from the standpoint of space-group theory; for this reason its earliest possible introduction is greatly to be desired.

In the accompanying tabulations the various determinations of structure are placed in the following classification: Class I, those structures which have been obtained with the aid of space-group results; Class II, those studied by the older methods; Class III, the few investigations which have been adequately carried through from a theoretical standpoint but which either are based upon insufficient data or on data which are in radical disagreement with the results of apparently equally good experimentation. Both Classes I and II are made subject to a further division:

Class IA, studies in which all possible arrangements have been considered.

Class IB, determinations in which space-group data have been used to pick out a structure but not to define all that may be possible. To this group belong the early investigations which used space-group information together with a few studies of crystals of relatively low symmetry.

Class IIA, possible atomic arrangements which in spite of the incompleteness of their determination the present writer considers to be almost certainly correct.

Class IIB, all other studies of crystal structure.

Not only must the value of determinations of structure be judged from the character of the general procedure used, but account must also be taken of the nature of the experimental data upon which they are based. This is especially true in a weighing of structures that must be assigned to Class II; for, while determinations based upon a proper use of the results of the theory of space-groups may be incomplete or inconclusive because of a lack of the proper data, they never will be indefinite. On the contrary, it frequently happens that the data underlying determinations of atomic arrangement by the older methods are of such a character as to make them little more than guesses.

At the present time there are four commonly employed methods of obtaining diffraction data from crystals. In weighing the value of these various methods for crystal structure work it

is necessary to consider not only the amount, but also the usefulness of the data supplied. Because of the lack of exact knowledge of the laws of scattering for X-rays, it is now necessary to employ a relatively large number of qualitative considerations in place of a few quantitative measurements. Laue photographs, in making easily available a large amount of such qualitative information, form the most valuable single method of collecting data. Of the others, powder experiments yield the most data by furnishing together reflections from planes of many crystal forms. At the same time this very advantage may present, especially in the case of crystals of low symmetry, an uncertainty in the correct choice of indices of observed reflections. The powder method has furthermore been commonly used to study the structures of substances which do not crystallize well. Such material is often contaminated with crystalline impurity which will itself give diffraction lines. There is consequently a great temptation to ascribe any reflections which are incompatible with a simple structure to this impurity. The dangers that may arise from this source are evident. The other two methods of producing diffraction phenomena, as is well known, consist in reflecting X-rays from single crystal faces: In the original Bragg experiment the positions and relative intensities of the reflections are recorded by an ionization chamber method; in the other case a photographic plate is used. The first of these, the spectrometer method, is open to grave error because unless particular care is taken reflections from faces other than the one supposedly under investigation may get into the detecting chamber and give either false readings of intensity or entirely new, and spurious, reflections.

The satisfactory method of experimentation has at hand all four of these means of accumulating diffraction data and uses those which are best adapted to the collection of the information required to establish the structure in hand. This procedure as yet has been followed only in relatively few instances.

Unfortunately an investigator often has become a devotee of some one method of collecting diffraction data and has applied it to the exclusion of all other procedures. This has been particularly true of the powder method and of the spectrometer method used as a basis of determinations which did not avail themselves of space-group information. The inadequacy of such

a method of approach to problems of crystal structure is shown in its results. A number of the more striking and conclusive illustrations of insufficiency are collected in the conclusion to this paper. In view of these practical examples of the breakdown of the older method of procedure and of the failure of any one method of collecting data to serve as a panacea for all crystal structure difficulties, it seems hardly necessary to point out again the necessity of a wider and less prejudiced use of all of the additional information which is available both from the theory of space-groups and from the conventional crystallography.

It may quite naturally be supposed that the unique character of a determination can be established for many Class II studies by a simple reworking of the original data. It happens, however, that most of the crystal structure papers published in this country contain no fundamental measurements. The responsibility for this does not rest entirely with the authors of these papers for conditions of publication have not permitted the printing of an adequate number of the experimental data upon which assignments of structure are based. This condition, over which crystal analysts themselves have only a relatively slight and indirect influence, is unfortunate in putting American writers at a serious disadvantage compared with their European coworkers. Economic circumstances, though, appear now to have so far adjusted themselves that it is no longer, if indeed it ever was, necessary to go to the extreme of reporting results without data of any sort. This in itself is a reason for rejoicing because a large number of the structures emanating from this country have appeared in this scant fashion, and it is certain that their ultimate fate must be to be completely disregarded. Continued improvement in opportunities for publication is a necessity for the welfare of crystal structure work, and it must be hoped that the time is not too far distant when structure determinations can be properly presented, and in English.

Very few of the determinations of crystal structure furnish any assurance, either by direct or indirect analysis, of the purity or even of the composition of the material under investigation. Methods have now so far developed that carefully made observations upon diffraction effects may be expected to have more than the transitory value of the earliest measurements. Thus there is no longer a reason for the disregard of so vital a factor

in the determination of the structure of a crystal as some knowledge of its actual composition.

Many studies of X-ray diffraction effects from crystalline materials have been made for purposes other than the direct study of atomic arrangements. They will not receive attention in the present review.

For order in presentation and ease of reference crystal structure investigations must be grouped according to some scheme which not only will include those now available, but will be sufficiently elastic to accommodate future work. For this purpose a system which has found general use in the classification of crystals themselves may naturally be followed. That used by Dana,[1] or the closely similar one of Groth,[2] particularly commend themselves by their completeness. In so far as they differ from one another, that of Groth is perhaps the more arbitrary, but it has the overwhelming advantage of including organic as well as inorganic crystals. Its major outline, for the crystals whose structures have been studied, is shown in Table I. A deviation from this classification in the discussion of individual crystals will, however, be made wherever it may prove convenient.

TABLE I.

The Order of Discussion of Crystal Structures.

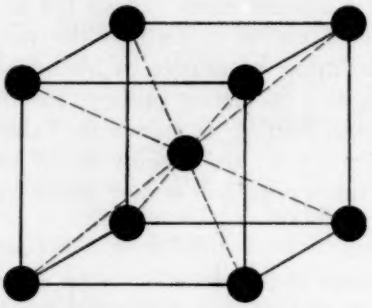
Elements.
Inorganic compounds not salts.
    Alloys, etc.
    Carbides, etc.
    Oxides.
    Hydroxides.
    Sulfides, selenides, etc.
Halides, cyanides, etc.
    Anhydrous compounds.
    Polyhalides.
Double (and triple) halides and cyanides.
Nitrates, chlorates, bromates, etc.
    Simple compounds.
    Hydrates and ammonates.
Carbonates.
Silicates, titanates, etc.
Sulfates, chromates, manganates, etc.
Borates, aluminates, ferrites, etc.
Organic compounds.

THE CRYSTAL STRUCTURES OF THE ELEMENTS.

THE METALS OF THE FIRST VERTICAL GROUP.

THE ALKALI METALS.—All work on the alkali metals has been carried out by the powder method. These metals are said to crystallize with a difficulty which becomes greater with increase in the atomic weight of the metal; the powder data consequently are rather meagre and quite insufficient for a thoroughly satisfactory determination. Considered, however, in connection with the structures of the better studied metals, it seems highly probable that the arrangements assigned to these metals are correct. The unit cube of each contains two atoms. This arrangement, which may be described as one that places one atom at each point

FIG. 1.



The unit cube of the body-centred arrangement of atoms in elements. The coördinate positions of the equivalent atoms in this unit are: 000; $\frac{1}{2}\frac{1}{2}\frac{1}{2}$.

of a body-centred space lattice, is shown in Fig. 1. The coördinate positions of the atoms within the unit are:

$$000; \qquad \tfrac{1}{2}\tfrac{1}{2}\tfrac{1}{2}.$$

Lithium.—Two investigations of lithium have been made. Early data [3] indicated that the arrangement was probably that of a body-centred cube 3.50A.U. on a side; subsequent measurements [4] are in agreement with such a structure having the same dimensions.

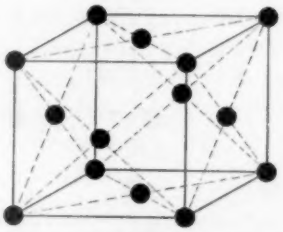
Sodium.—Considerable difficulty was experienced in preparing crystalline sodium and the best obtainable photographs were darkened by the presence of quantities of amorphous metal. The relatively few lines found are said to agree in position with those of a body-centred cube [3] of side $a = 4.30$A.U.

Potassium.—An attempt [3] to prepare potassium at room temperature which would give any diffraction pattern failed. Such

a pattern has been obtained [5] at −150° C., but all evidence of crystallinity had vanished at −20° C. The diffraction results observed at −150° C. by a slow rotation through small angles are considered to agree best with a body-centred structure 5.20A.U. on a side. No data are published by which the value of this assignment of structure may be gauged.

THE SUB-GROUP ELEMENTS.—Diffraction measurements have been made upon all three metals: Copper, silver and gold. With the exception of some powder measurements incidental to a study of sputtered films all data have been obtained from spectrometric observations upon not more than three crystal faces. All agree in assigning an arrangement which places one atom at

FIG. 2.



The face-centred arrangement of the atoms in elements. The coördinate positions of four equivalent atoms within the unit are: 000; $\frac{1}{2}\frac{1}{2}0$; $\frac{1}{2}0\frac{1}{2}$; $0\frac{1}{2}\frac{1}{2}$.

each point of a face-centred cubic lattice (Fig. 2). The coördinates of the typical atomic positions within the unit cube are thus:

$$000;\quad \tfrac{1}{2}\tfrac{1}{2}0;\quad \tfrac{1}{2}0\tfrac{1}{2};\quad 0\tfrac{1}{2}\tfrac{1}{2}.$$

In spite of the insufficiency of the data it is probable that these assignments are correct.

Copper.—Reflections were obtained [6] from the (100), (110) and (111) faces of a natural crystal. The length of the side of the unit containing four atoms was determined as: $a = 3.60$A.U.

Silver.—Similar spectrometer measurements [7] have been recorded for natural crystals of silver. The length of the side of the unit: $a = 4.06$A.U. It also has been stated that powder measurements [8] are in agreement with a face-centred structure of the same size, but no data are given.

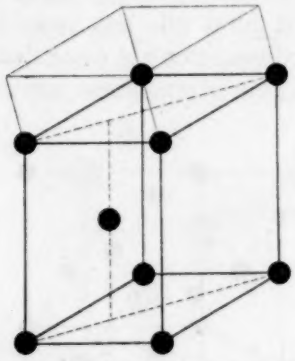
Gold.—Only a reflection from an octahedral face was obtained. From this [9] the length of the side of the unit cube: $a = 4.07$A.U. Powder measurements (no data supplied) [8] are

said to agree with a face-centred arrangement having a unit 4.08A.U. on a side.

THE METALS OF THE SECOND VERTICAL GROUP.

THE TRANSITIONAL ELEMENTS BERYLLIUM AND MAGNESIUM.—Both of these metals crystallize in the hexagonal system. Primarily on the ground of powder data they have been assigned an atomic arrangement which is a near approach to the closest

FIG. 3.



The close-packed hexagonal arrangement of the atoms in elements. The coördinate positions of the two equivalent atoms within this unit cell are: 000; ⅓, ⅔, *u*. Unless the crystal possesses holohedral symmetry the parameter *u* will not be exactly ½. The hexagon completed by the light lines at the top of the figure serves to show the relation of this unit cell to the large hexagonal prism.

packing of solid spheres. This structure, shown in Fig. 3, has atoms in the coördinate positions:

$$000; \qquad \tfrac{1}{3},\tfrac{2}{3},u.$$

The powder data do not seem capable of establishing the precise value of u. Other possible structures are taken account of only for magnesium. In no case, however, is a treatment given which is based upon space-group theory. A more complete study of one of these metals would be desirable, particularly if it could be obtained in crystals large enough for Laue photographic measurement.

Beryllium.—This structure was assigned[10] to powdered beryllium in stating the arrangement as two interpenetrating hexagonal lattices, the exact manner of intermeshing of which could not be determined with accuracy. The length of the side of the unit cell containing two atoms (as illustrated in Fig. 3): a (the base) = 2.283A.U.; c (the height) = 3.607A.U. The result-

ing axial ratio is in agreement with the crystallographically determined $c:a = 1.580$.

Magnesium.—Magnesium has been given the structure already discussed on the basis of powder data and spectrographic data obtained [3, 11] by recording reflections from the basal section of a single crystal. The dimensions of the unit cell: $a = 3.22$A.U.; $c = 5.23$A.U. The results using a modified form of powder spectrograph [12] are considered to be in agreement with a structure built up of two interpenetrating hexagonal lattices, the units of which each have the dimensions: $a = 3.23$A.U.; $c = 5.25$A.U. This is equivalent to the one already described. Though the manner of interpenetration of these lattices, that is, the value of u, could not be determined, these data are held not to be compatible with $u = \frac{1}{2}$.

THE ALKALINE EARTH METALS.—*Calcium* has been studied. Powder photographic data [27, 13] are believed to point to a face-centred cubic arrangement (Fig. 2). A comparison photograph of calcium oxide was prepared in order to eliminate its lines from the spectrum of metallic calcium. The length of the side of the unit cube containing four atoms: $a = 5.56$A.U.

THE SUB-GROUP ELEMENTS ZINC, CADMIUM AND MERCURY.—Powder diffraction data have been used to assign crystal structures to all three of these metals. Following the same general mode of procedure, the same closest-packed arrangement has been given to the first two as to magnesium. Crystalline mercury does not appear to have this structural arrangement and will be discussed separately.

Zinc.—The powder data [19] are considered to be in agreement with a unit cell for which $a = 2.670$A.U. and $c = 4.966$A.U. As with the other metals crystallizing similarly the possibility of the parameter u being other than one-half has not been considered. The axial ratio corresponding to this unit, $c:a = 1.860$, is not in agreement with the crystallographically determined ratio, $c:a = 1.356$. Whatever the explanation of this discrepancy may be, it is clear that a further study of zinc will be profitable.

Cadmium.—The same dilemma exists with respect to the axial ratio of cadmium crystals. The X-ray powder data [19] are considered to agree with a unit cell for which $a = 2.980$A.U. and $c = 5.632$A.U. The corresponding axial ratio is $c:a = 1.89$ as contrasted with the crystallographically determined 1.335.

Mercury.—Powder photographs have been used to establish two different structures for crystals of mercury. The results of one study [15] are said to be in agreement with a grouping of the mercury atoms at the corners of a simple rhombohedron for which $a = 3.025$A.U. and α (the angle between the axes) $= 70°31.7'$; this is said to correspond in terms of hexagonal axes to $a = 3.493$A.U. and $c : a = 1.9365$. The hexagonal equivalent of a simple rhombohedral arrangement contains three atoms within the unit cell. In this paper no other possible atomic groupings are treated. The other hexagonal structure [16] places four atoms within the unit cell. After a treatment of the various arrangements with this number of atoms in the unit which the results of the theory of space-groups suggest, an arrangement is chosen which places mercury atoms in the coördinate positions: 000; $0,0,u+\frac{1}{2}$; $2/3, 1/3, \frac{1}{2}$; $2/3, 1/3, u$, where the value of the parameter u was not determinable. The measurements of the first paper were taken at $-115°$ C., those of the second at the temperature of carbon dioxide snow. Both determinations have practically the same value for the axial ratio, and it may be doubted if the explanation of the conflict between these two studies lies in the existence of two modifications of mercury. A reworking of these data is urgently needed. In the meantime any decision as to their probable correctness must be held in abeyance, though from a theoretical standpoint the second [16] determination is incomparably better done.

THE METALS OF THE THIRD VERTICAL GROUP.

Only two metals of this group have been studied: Aluminum and indium. Both have been examined only with powder data without any treatment making use of the results of the theory of space-groups.

Aluminum.—Two independent determinations [3, 17, 18] of the structure of metallic aluminum assign a face-centred cubic arrangement (Fig. 2) to its atoms. These two studies place the side of the unit cube: $a = 4.05$A.U.[3] and $a = 4.07$A.U.[18]

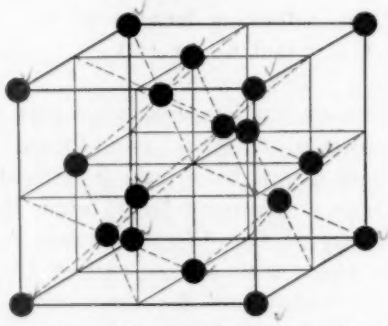
Indium.—Powder photographic data from indium [19] are said to be in agreement with an arrangement of its atoms at the points of a face-centred tetragonal lattice of axial ratio $c : a = 1.06$. The lengths of the edges of this unit are $a = 4.58$-

A.U., $c = 4.86$A.U. No other tetragonal structure which might be in agreement with these data has been considered.

THE ELEMENTS OF THE FOURTH VERTICAL GROUP.

THE TRANSITIONAL ELEMENTS CARBON AND SILICON.—The crystal structure of carbon in various physical states has been studied. All of the diffraction patterns thus obtained, with the exception of the one from diamond, are identical with that exhibited by graphite. Laue photographs, spectrometer measurements and powder data have all been examined in the light of more recent procedure. Powder data have been used by

FIG. 4.



The "diamond" type of arrangement of the atoms of elements. The coördinate positions of the eight equivalent atoms within the unit are: 000; $\frac{1}{2}\frac{1}{2}$0; $\frac{1}{2}$0$\frac{1}{2}$; 0$\frac{1}{2}\frac{1}{2}$; $\frac{1}{4}\frac{1}{4}\frac{1}{4}$; $\frac{3}{4}\frac{3}{4}\frac{1}{4}$; $\frac{3}{4}\frac{1}{4}\frac{3}{4}$; $\frac{1}{4}\frac{3}{4}\frac{3}{4}$.

two sets of observers to assign two totally different structures to graphite.

Several measurements, all of which give it the diamond structure, have been made of the powder reflections from silicon.

Carbon.—The coördinate positions of the atoms of carbon within the unit cube of the diamond according to the accepted structure are as follows (Fig. 4):

$$000;\ 0\tfrac{1}{2}\tfrac{1}{2};\ \tfrac{1}{2}\tfrac{1}{2}0;\ \tfrac{1}{2}0\tfrac{1}{2};\ \tfrac{1}{4}\tfrac{1}{4}\tfrac{1}{4};\ \tfrac{3}{4}\tfrac{3}{4}\tfrac{1}{4};\ \tfrac{3}{4}\tfrac{1}{4}\tfrac{3}{4};\ \tfrac{1}{4}\tfrac{3}{4}\tfrac{3}{4}.$$

The length of the side of this unit cube, as determined by the original spectrometric measurements [20, 85] is 3.55A.U. The recorded powder data [3] give practically the same value: $a = 3.56$A.U.

Before the time of X-ray methods of investigation the symmetry of graphite was in doubt. A Laue photograph,[21] as well as all of the powder data and the most reliable crystallographic indications, make it hexagonal. One set of powder data [22, 23] is thought to be in agreement with a rhombohedral structure of

considerable complexity of atomic arrangement. The other set [3, 24] is held to disagree with this structure and to establish one that is hexagonal. Graphite presents another case of the ease with which powder photographic data can go astray in the determination of the structures of any but the simplest crystals when unaided by definite crystallographic information. Not only is further work necessary for the reconciling of these conflicting results, but it is imperative that the results of space-group theory be invoked in the discussion of all possible arrangements before any structure can be accepted for graphite.

Silicon.—Three assignments [3, 17, 25, 26] of structure based upon powder data all give silicon the diamond arrangement (Fig. 4). They yield the following lengths of the side of the unit cube: $a = 5.46$A.U., 5.40A.U., 5.43A.U., with the last most probably correct.

THE FIRST SUB-GROUP ELEMENTS OF THE FOURTH GROUP TITANIUM, ZIRCONIUM, CERIUM AND THORIUM.—The structures of all of these metals have been investigated with powder photographs without a treatment based upon the results of the theory of space-groups. The diffraction data for the first three are considered to agree with a close-packed hexagonal arrangement analogous to that found for magnesium (Fig. 3). No account is taken of the possibility of the parameter u which defines the z coördinate of the second atom within the unit cell being other than one-half. For this reason, even if these structures are essentially correct, the interatomic distances calculated from them cannot be taken as more than approximate. Two independent determinations of thorium assign it to the closely related cubic close-packed arrangement (Fig. 2). Cerium is said probably to have a second cubic modification which is like thorium and can exist along with the hexagonal structure. No data have as yet been published for any of these studies except one on thorium.[12]

Titanium.—The dimensions [27, 28] of the unit cell: $a = 2.97$A.U.; $c = 4.72$A.U., corresponding to the axial ratio $c : a = 1.59$.

Zirconium.—The dimensions [28] of the unit cell: $a = 3.23$A.U., $c = 5.14$A.U., corresponding to the axial ratio $c : a = 1.59$.

Cerium.—Cerium [28] is probably dimorphous, crystallizing in both the hexagonal and cubic close-packed arrangements. The dimensions of the hexagonal unit are stated as: $a = 3.65$A.U.,

$c = 5.96$A.U., the axial ratio being $c : a = 1.62$. The cubic modification (Fig. 2) is reported to have a length of side of $a = 5.12$A.U.

Thorium.—The two determinations[28, 12] of structure give the lengths of the sides of the unit cube (Fig. 2): $a = 5.04$A.U. and 5.12A.U., respectively.

THE SECOND SUB-GROUP ELEMENTS OF THE FOURTH GROUP GERMANIUM, TIN AND LEAD.—Measurements have been made upon all three of these metals, the first two with the aid of powder photographs, the last by a single reflection from a (111) crystal face. Germanium and gray tin have been given the diamond arrangement (Fig. 4), white tin a tetragonal structure, and lead one that is face-centred cubic (Fig. 2).

Germanium.—Powder data[24, 29] are said to be in agreement with a diamond arrangement, the edge of the unit cube of which (Fig. 4) is 5.63A.U. or 5.61A.U. Data have been published only for the second determination.[29]

Tin.[30]—Gray tin is assigned the diamond arrangement (Fig. 4), the length of the side of the unit cube being: $a = 6.46$A.U. The unit of white tin is given as a tetragonal prism containing three atoms in the coördinate positions: 000; $\frac{1}{2}0\frac{1}{2}$; $0\frac{1}{2}\frac{1}{2}$. The published dimensions of this unit are: $a = 5.84$A.U., $c = 2.37$A.U., corresponding to the axial ratio $c : a = 0.406$. Apparently this study with powder photographic data offers only a possible atomic arrangement, at least until a complete treatment based upon the results of the theory of space-groups has been carried out.

Lead.—A single reflection[9] from a (111) face of a lead crystal is in agreement with a face-centred cubic unit (Fig. 2) for which the length of the unit side is: $a = 4.91$A.U. The need of more work upon this metal is obvious.

THE ELEMENTS OF THE FIFTH VERTICAL GROUP.

The structure of neither of the transitional elements has been studied. Two of the first sub-group elements, vanadium and tantalum, and two of the elements of the second sub-group, antimony and bismuth, have given diffraction data.

THE FIRST SUB-GROUP ELEMENTS OF THE FIFTH GROUP VANADIUM AND TANTALUM.—A body-centred cubic arrangement has been assigned to both of these metals on the basis of powder photographic data.

Vanadium.[24]—The length of the side of the unit cube con-

taining two atoms (Fig. 1) is given as $a = 3.04$A.U. No data have as yet been published.

Tantalum.[27, 19]—The length of the side of the unit (Fig. 1) is 3.272A.U.

THE SECOND SUB-GROUP ELEMENTS OF THE FIFTH GROUP ANTIMONY AND BISMUTH.—Both powder data and spectrometric measurements have been accumulated for bismuth while only spectrometric data are available for antimony. Both have the symmetry of the hexagonal system. The different structures that have been assigned to each of them offer another example of the results to be expected from the application of the older procedure of crystal structure study. Recent spectrometer measurements are in disagreement with the early structure which gave both antimony and bismuth a diamond arrangement [34] distorted along the trigonal axes so that the unit cubes became rhombohedrons. The later data agree in giving to the two elements a similar atomic marshalling, but the ratio of the intensities of reflection from the various orders from the (111) face, particularly in the case of antimony, are very different, so that the positions of the atoms are not the same in the two results. Powder photographic data for bismuth were thought to give evidence for still another atomic arrangement.

Antimony.—A detailed consideration of the existing determinations is not justified. The recently proposed structure is described as a rhombohedral one containing eight atoms within the unit cell: Four lying upon a face-centred arrangement possessing rhombohedral symmetry and the other four upon another similar arrangement which is displaced along the trigonal axes of the first by an amount which differs for the two observers.[31, 32]

Bismuth.—Bismuth has been given three structures. The original distorted diamond arrangement [34] is considered to have been disproved by the more recent spectrometric observations,[32, 33] which themselves are said to agree with a structure similar to the one assigned to antimony. The structure deduced from powder data [8] is a simple rhombohedral arrangement of bismuth atoms.

THE ELEMENTS OF THE SIXTH VERTICAL GROUP.

The Transitional Element Sulfur.—Spectrometric measurements [35] have been made upon crystals of orthorhombic sulfur. Especially when viewed in the light of the difficulties encountered

in deducing the structure of the simpler bismuth, for example, it must be clear that these observations are of little value towards establishing atomic arrangement in sulfur.

THE FIRST SUB-GROUP ELEMENTS OF THE SIXTH GROUP CHROMIUM, MOLYBDENUM AND TUNGSTEN.—All of these elements have been studied by the unaided powder method. They are said to be cubic with a body-centred arrangement of their atoms (Fig. 1).

Chromium.[19]—The unit cell (Fig. 1) has a length of side: $a = 2.895$A.U.

Molybdenum.—Two determinations[19, 36] of the length of the edge of the unit cube give $a = 3.143$A.U. and 3.08A.U., respectively.

Tungsten.—The two studies[37, 19] of this structure place $a = 3.18$A.U. and 3.150A.U., respectively. The latter determination was based upon a comparison photograph of molybdenum and tungsten for which no data have been furnished.

THE SECOND SUB-GROUP ELEMENTS OF THE SIXTH GROUP.—No attempts have been made to determine the arrangement of the atoms in either selenium or tellurium crystals.

THE ELEMENTS OF THE SEVENTH VERTICAL GROUP.

No diffraction measurements have been made upon any element of this group.

THE ELEMENTS OF THE EIGHTH VERTICAL GROUP.

Structures, based upon powder photographic data, have been given to all of the metals of this group. Spectrographic measurements have also been made upon individual crystals of iron[3] containing about 3½ per cent. of silicon. The data from this alloy were in agreement with the powder data from pure iron. Of these metals, rhodium, palladium, iridium and platinum are given the face-centred cubic arrangement (Fig. 2); ruthenium and osmium the close-packed hexagonal grouping (Fig. 3); cobalt is said to crystallize in both of these forms which can coexist at ordinary temperatures; α- and β-iron are body-centred cubic (Fig. 1), while γ-iron, stable at 1000° C., is face-centred; and nickel, which at first was said to have coexistent body-centred and face-centred cubic structures, is now described only in the face-centred modification.

Iron.—Two determinations [38, 3, 39, 40, 41] of the structure of the low temperature form of iron place the length of the side of the unit cube containing two atoms (Fig. 1) at 2.86A.U. and 2.87A.U. The atomic arrangement of the γ-form [40, 41] at 1000° C. is given as face-centred (Fig. 2), the length of the edge of the unit cube being 3.60A.U.

Nickel.—As originally described,[3] nickel had both a face-centred and a body-centred modification. Subsequently it is stated [19, 39] that only the diffraction patterns of a face-centred cubic arrangement (Fig. 2) 3.540A.U. on a side could be found. The other study [12] of nickel also gives it a face-centred structure for which $a = 3.53$A.U.

Cobalt.[39, 19]—Two forms of cobalt can be prepared either practically free from one another or mixed in various proportions. For the face-centred cubic arrangement (Fig. 2) $a = 3.554$A.U.; the hexagonal close-packed possesses a unit with a base $a = 2.514$-A.U. and an axial ratio $c : a = 1.633$. This axial ratio is precisely that of the closest packing of spheres.

Ruthenium.[27, 19]—The close-packed hexagonal unit (Fig. 3) has the dimensions: $a = 2.686$A.U., $c = 4.272$A.U., corresponding to the axial ratio $c : a = 1.59$.

Rhodium.[19]—For the face-centred cubic structure (Fig. 2): $a = 3.820$A.U.

Palladium.[27, 19, 42]—Face-centred cubic (Fig. 2). Two determinations give $a = 3.950$A.U. and $a = 3.90$A.U. It has also been noted that when metallic palladium absorbs hydrogen, it swells several per cents. without other change in structure.

Osmium.[28]—Hexagonal close-packed arrangement (Fig. 3). The unit cell has the dimensions: $a = 2.714$A.U., $c = 4.32$A.U., corresponding to the axial ratio $c : a = 1.59$.

Iridium.[27, 19]—Face-centred cubic arrangement (Fig. 2). $a = 3.805$A.U.

Platinum.[27, 19, 8]—Face-centred cubic arrangement (Fig. 2). Two determinations of the dimensions of this unit (the second upon sputtered films of metal) place $a = 3.930$A.U. and 4.02-A.U., respectively.

SUMMARY OF THE STRUCTURES OF THE ELEMENTS.

Mention has now been made of the various attempts to determine the arrangement of the atoms in crystals of the chemical elements. The results of these studies are summarized in Table II.

TABLE II.

The Crystal Structures of the Metals.

Element.	System of Symmetry.	Type of Arrangement.	Text Figure of Unit Cell.	Dimensions of Unit Cell.	Class of Determination.
Lithium	Cubic	Body-centred	Fig. 1	$a = 3.50$ A. U.	IIA
Sodium	Cubic	Body-centred	Fig. 1	$a = 4.30$	IIA
Potassium (−150°)	Cubic	Body-centred	Fig. 1	$a = 5.20$	IIA?
Copper	Cubic	Face-centred	Fig. 2	$a = 3.60$	IIA
Silver	Cubic	Face-centred	Fig. 2	$a = 4.06$	IIA
Gold	Cubic	Face-centred	Fig. 2	$a = 4.07$; 4.08	IIA
Berylhium	Hexagonal	Hex. close-packed	Fig. 3	$a = 2.283$; $c = 3.607$	IIA
Magnesium	Hexagonal	Hex. close-packed	Fig. 3	$a = 3.23$, 3.22; $c = 5.25$, 5.23	IIA
Calcium	Cubic	Face-centred	Fig. 2	$a = 5.56$	IIA
Zinc	Hexagonal	Hex. close-packed	Fig. 3	$a = 2.670$; $c = 4.966$	IIA
Cadmium	Hexagonal	Hex. close-packed	Fig. 3	$a = 2.980$; $c = 5.632$	IIA
Mercury	Hexagonal ?	.....	.....	.....	III
Aluminum	Cubic	Face-centred	Fig. 2	$a = 4.05$, 4.07	IIA
Indium	Tetragonal	.....	.....	.....	IIB
C (diamond)	Cubic	Diamond	Fig. 4	$a = 3.55$, 3.56	IIA
C (graphite)	Hexagonal	.....	.....	.....	IIB
Silicon	Cubic	Diamond	Fig. 4	$a = 4.53$, 4.50, 4.56	IIA
Titanium	Hexagonal	Hex. close-packed	Fig. 3	$a = 2.97$; $c = 4.72$	IIA
Zirconium	Hexagonal	Hex. close-packed	Fig. 3	$a = 3.23$; $c = 5.14$	IIA
Cerium	Hexagonal	Hex. close-packed	Fig. 3	$a = 3.65$; $c = 5.96$	IIA?
Cerium	Cubic	Face-centred	Fig. 2	$a = 5.12$	IIA?
Thorium	Cubic	Face-centred	Fig. 2	$a = 5.04$, 5.12	IIA
Germanium	Cubic	Diamond	Fig. 4	$a = 5.63$; 5.61	IIA
Tin (gray)	Cubic	Diamond	Fig. 4	$a = 6.46$	IIA
Tin (white)	Tetragonal	.....	.....	.....	IIB
Lead	Cubic	Face-centred	Fig. 2	$a = 4.91$	IIA?
Vanadium	Cubic	Body-centred	Fig. 1	$a = 3.04$	IIA
Tantalum	Cubic	Body-centred	Fig. 1	$a = 3.272$	IIA
Antimony	Hexagonal	.....	.....	.....	IIB
Bismuth	Hexagonal	.....	.....	.....	IIB
Sulfur	Orthorhombic	.....	.....	.....	IIB
Chromium	Cubic	Body-centred	Fig. 1	$a = 2.895$	IIA
Molybdenum	Cubic	Body-centred	Fig. 1	$a = 3.143$, 3.08	IIA
Tungsten	Cubic	Body-centred	Fig. 1	$a = 3.18$, 3.150	IIA
Alpha iron	Cubic	Body-centred	Fig. 1	$a = 2.86$, 2.87	IIA
Gamma iron	Cubic	Face-centred	Fig. 2	$a = 3.60$ at 1000°	IIA
Nickel	Cubic	Face-centred	Fig. 2	$a = 3.53$, 3.54	IIA
Cobalt	Cubic	Face-centred	Fig. 2	$a = 3.554$	IIA
Cobalt	Hexagonal	Hex. close-packed	Fig. 3	$a = 2.514$; $c = 4.105$	IIA
Ruthenium	Hexagonal	Hex. close-packed	Fig. 3	$a = 2.686$; $c = 4.272$	IIA
Rhodium	Cubic	Face-centred	Fig. 2	$a = 3.820$	IIA
Palladium	Cubic	Face-centred	Fig. 2	$a = 3.950$, 3.90	IIA
Osmium	Hexagonal	Hex. close-packed	Fig. 3	$a = 2.714$; $c = 4.32$	IIA
Iridium	Cubic	Face-centred	Fig. 2	$a = 3.805$	IIA
Platinum	Cubic	Face-centred	Fig. 2	$a = 3.930$, 4.02	IIA

INORGANIC COMPOUNDS NOT SALTS.

ALLOYS.—Most of the accumulated information concerning the structures of alloys is the result of two investigations using the powder method. In alloys [43] from pure nickel to 70 per cent. Fe – 30 per cent. Ni the structure is said to be face-centred cubic; beyond 70 per cent. Fe it is body-centred cubic. Similarly up to 80 per cent. of iron atoms[43] can be replaced by cobalt atoms before there is a shift from a body-centred cubic arrangement. With amounts of cobalt increasing beyond 80 per cent. the structure is said to pass through a mixture of face-centred and body-centred forms, pure face-centred and finally a mixture of face-centred cubic and hexagonal closest packed. The results of the study of copper-zinc alloys [43] are much more complicated, passing it is said through face-centred cubic (for copper), body-centred cubic, rhombohedral, and finally hexagonal arrangements (for zinc). In reporting this study [43] no numerical data of any sort (except compositions of alloys) are given, so that neither can the structures assigned be checked nor can any dimensional changes with composition be followed. In view of the probably correct simple structures of the metals themselves, it is likely that the nickel-iron and cobalt-iron alloys are correct, but when the complexity of the copper-zinc series is taken into account, it is impossible to lay great reliance upon these results as determinations of atomic arrangement. A 20 per cent. nickel-steel, which normally showed a practically pure face-centred cubic form, was made to develop strongly the body-centred modification after being chilled in liquid air.

Powder experiments [41, 44] upon nickel and manganese steels and upon other steels after various physical treatments have been described. It is concluded that in austenite the atoms have a face-centred arrangement, in martensite and in ordinary quickly drawn steel hardened at 1275° C. the atoms have the body-centred arrangement characteristic of α-iron.

The following [45] has been published upon alloys of silver-palladium and of silver-gold: "An X-ray analysis of two graded series of alloys, extending from pure silver to pure palladium, and from pure silver to pure gold, shows that the edge of the unit cube in silver decreases progressively with the addition of palladium, but remains practically unchanged by the addition of gold. The effects of cold-work and of annealing have been observed.

Accurate values for the edges of the unit cubes, and corresponding densities of the pure metals and alloys have been obtained." *

The investigation of the natural alloy of iridium and osmium, known as iridosmium,[46] furnishes what is from the standpoint of crystal structure determination by far the most satisfactory investigation yet made of any metal. Taking the diffraction data from Laue photographs and making use of the results of the theory of space-groups, it is shown that these data require the close-packed hexagonal arrangement of atoms. The parameter u defining the position of the second atom within the unit cell is taken as one-half, though the compelling reason for precisely this value is not clear. It is unfortunate that the specimen used in this study was of unknown chemical composition so that the dimensions resulting from it have little significance.

CARBIDES, ETC.

Carborundum, SiC.—The studies that have been made of the crystal structure of carborundum furnish another and striking example of the insufficiency of the older methods of investigation. Crystallographic information upon carborundum has given it hexagonal symmetry with an indication of trigonal characteristics. Recently evidence [47] of a purely crystallographic sort has been adduced which points to the existence of three distinct types of crystals. Laue photographs [48] have subsequently been made from crystals of these three supposed kinds. Two of the modifications appear to be truly hexagonal, the third is surely trigonal. The relations supposed to exist between these forms are unusual for independent modifications of a substance.

Three investigations have been made of the structure of carborundum: One [49] by the original spectrometer technic, one with powder data [50] (neither of these has made any use of the results of the theory of space-groups) and one [51] that makes use of Laue photographic and spectrographic data and of space-group results. From the spectrometric data a structure was deduced [49] which was like that of the diamond if half of the carbon atoms are replaced by silicon atoms and if the silicon atoms as a whole are considerably displaced along trigonal axes. A Laue photo-

* A detailed account of these experiments has recently appeared.[351] The following dimensions for gold, silver and palladium are included: a = 4.075A.U.; a = 4.080A.U.; a = 3.900A.U.

graph, published by one of these authors in a different place,[52] shows a hexagonal symmetry which (if it is due to an untwinned specimen) is not in agreement with the assigned structure. Calculations[53] based solely upon electromagnetic theory (the details of which are not given) have been thought to make the spectrometer results agree with an undistorted diamond arrangement. Later powder data[50] are said to give the lines of both the cubic and hexagonal close packing; this is considered to show that crystals of carborundum are a combination of both of these arrangements. Only in face of information of the most convincing character would one be justified in seriously considering the reality of such a hybrid as this; as yet no data of any sort have appeared. The third investigation,[51] which made use principally of Laue photographic data, was carried out with a full awareness of the crystallography of carborundum. A structure for the second type has been obtained which contains twenty-four chemical molecules within the unit cell. It is stated that the other two forms likewise have units of the same absolute size and contain twenty-four molecules. From the discussion which accompanies this study of structure, it is not clear that so large a unit cell must be chosen, and it does not seem permissible to make a definite decision concerning the structure of carborundum until the investigations have been made more complete. In the meantime it is apparent that the unaided spectrometric and powder photographic data have proved themselves totally inadequate for handling this crystal.

OXIDES.

MONOXIDES OF UNIVALENT ELEMENTS.—Diffraction data have been collected from three of these oxides: Silver oxide, cuprous oxide and ice. For the first of these only powder data are at hand, for the second both powder and rough spectrometric measurements, while for ice diffraction data by all methods have been published.

Ice, H_2O.—A Laue photograph[54] has been prepared which is said to assign ice to the hexagonal division of the hexagonal system with an axial ratio of $c:a = 1.678$. Proceeding upon the assumption that such a Laue photograph really was obtained from a single crystal and not from a twinned trigonal form, a theoretically well-developed study[55] has been given of the atomic arrangement. Two molecules are found associated with a unit of the

dimensions: $a = 3.46$A.U., $c = 5.53$A.U. The data are not sufficient to place the atoms accurately within this unit. According to spectrometric results [56] the hexagonal unit has a length $a = 4.74$A.U. and a height $c = 6.65$A.U., corresponding to the axial ratio $c : a = 1.4026$. Four molecules are contained within this unit cell, the coördinate positions (presumably of the oxygen atoms) being given as 000; $1/3, 2/3, 1/z$; $1/3, 2/3, 1/2$; 0, 0, $(z+2)/2z$, where the value of z is indeterminate. The powder photographic data,[57] on the other hand, have been interpreted to yield a unit of yet another size: $a = 4.52$A.U., $c = 7.32$A.U.; axial ratio, $c : a = 1.62$. Though these axial ratios are appropriately related to one another, one as the result of a rotation through 30° with respect to the other, the absolute dimensions of the unit cells in the last two instances are not similarly related. The close approximation of the axial ratio taken from powder data to that of the closest packed grouping of spheres ($c : a = 1.633$) is taken as an indication that the molecules of water are associated into H_4O_2 groups which are themselves closely packed. As an unconscious illustration of the ease with which different structures can be assigned to a crystal by this older procedure, a still different interpretation [58] has been given to these same data.

Of the various studies upon ice only one [55] has any worth as a determination of the atomic arrangement. On the other hand, the best experimental data are powder measurements.[57] In view of the disagreement between these investigations in the determination of the size and shape of the correct unit cell, and because the data open to the least question do not accompany the best study of structure, it is not permissible to decide which, if any, of these studies may be correct.

Cuprite, Cu_2O.—Spectrometric data [59] have been obtained from crystals of cuprite, but have not been reported except in a rough graphical form. They appear to agree with a unit cube which contains two chemical molecules and has the length of side: $a = 4.32$A.U. The coördinate positions within this unit cube (Fig. 5) are:

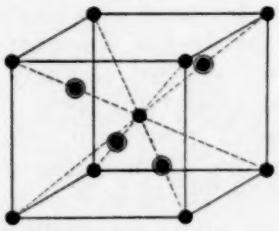
Copper: $\frac{1}{4}\frac{1}{4}\frac{1}{4}$; $\frac{3}{4}\frac{3}{4}\frac{1}{4}$; $\frac{3}{4}\frac{1}{4}\frac{3}{4}$; $\frac{1}{4}\frac{3}{4}\frac{3}{4}$.
Oxygen: 000; $\frac{1}{2}\frac{1}{2}\frac{1}{2}$.

Powder photographic data,[60] concerning which nothing has been published, are said to yield $a = 4.26$A.U. Very recently [61] an

adequate treatment of powder photographic data leads to the same structure, also with $a = 4.26$A.U.

Silver Oxide, Ag_2O.—A study[62] of the structure of this substance has been carried out with use of the results of the theory of space-groups, the data being taken from powder photographs. It is shown that the cuprite arrangement (Fig. 5) given above is the only possible structure if the unit cube is a simple one containing two, and not sixteen, chemical molecules. Furthermore, no lines were found upon the photographs which were not in agreement with this smaller unit. The length of its side was

FIG. 5.



The unit cube of the "cuprite arrangement." In the compound R_2X, the atoms of X are indicated in this figure by the solid circles.

found to be $a = 4.77$A.U. Another study[60] of silver oxide, data upon which have never been published, gives a unit cell of length 4.69A.U. This structure has recently been confirmed[61] by another treatment of powder data which yields a dimension lying between the other two: $a = 4.718$A.U.

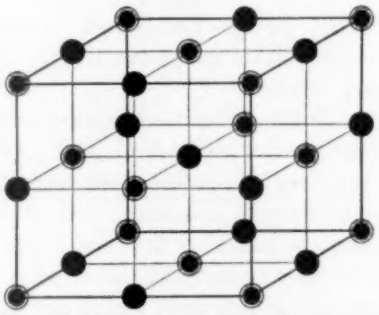
MONOXIDES OF THE DIVALENT METALS.—Except for magnesium oxide and zinc oxide only powder photographic data have been collected. Aside from beryllium oxide and zinc oxide which have a hexagonal symmetry, and cupric oxide which is triclinic, all have been given a "sodium chloride arrangement" (Fig. 6). The detailed treatment of the case of magnesium oxide * has shown that this latter structure is the only one which may properly be deduced from the existing experimental data. It seems quite certain, though the published data are in many cases scarcely convincing, that the other cubic oxides have this same structure. Zinc oxide has received a thorough treatment with data from Laue and powder photographic and spectrometric sources and

* See also the analogous treatment of sodium chloride by P. Niggli, "Geometrische Krystallographie des Discontinuums," p. 435, etc., Leipzig, 1919.

from the general similarity of their powder data it is probable that beryllium oxide has the same type of structure. A lengthy discussion of powder photographic data is believed to give a distorted "sodium chloride arrangement" of the atoms in cupric oxide.

Cupric Oxide, CuO.—Taking the data from powder photographs, a structure has been deduced [61] for this triclinic crystal which conforms with the crystallographic data.[61, 70] Though this arrangement, which is a distortion of that of sodium chloride (Fig. 6), does not appear to be uniquely determined, it is probably

FIG. 6.



The unit cube of the "sodium chloride arrangement." In the compound RX either the atoms of R or those of X may be represented by the solid circles.

correct. For a detailed description reference must be made to the original article.

Beryllium Oxide, BeO.—Two studies have been made of powder photographic data from beryllium oxide. As a result of one of them [63] it was given the "sodium chloride arrangement," but in view of its well-known hexagonal symmetry little significance can be attached to this work. The experimental results of the other investigation [10] are said to correspond to a unit hexagonal cell of length of side $a = 2.696$A.U. and height $c = 4.394$A.U., and to be at least consistent with the "zinc oxide structure" (Fig. 7) to be described below.

Magnesium Oxide, MgO.—Besides the powder photographic data,[65, 66, 63, 67, 26, 69, 70] which have been collected by various observers, Laue photographs were studied in connection with the application of the results of the theory of space-groups.[68] The structure is that of the "sodium chloride arrangement" (Fig. 6),

in which the atoms have the following coördinate positions within the unit cube:

Magnesium:	000;	$0\frac{1}{2}\frac{1}{2}$;	$\frac{1}{2}\frac{1}{2}0$;	$\frac{1}{2}0\frac{1}{2}$.
Oxygen:	$\frac{1}{2}\frac{1}{2}\frac{1}{2}$;	$\frac{1}{2}00$;	$00\frac{1}{2}$;	$0\frac{1}{2}0$.

Various determinations of the length of the side of the unit cube have been published: 4.22 ± 0.02A.U.; 4.19A.U.; 4.20A.U.; 4.18A.U.; and 4.22A.U. From these values the most probable one appears to be 4.20A.U.

Calcium Oxide, CaO.—Of the reported studies,[26, 63, 66] one [63] contains data in substantiation of the "sodium chloride structure" (Fig. 6). The length of the side of the unit cube is variously stated as: 4.74A.U.; 4.77 ± 0.05A.U.; 4.84A.U.

Strontium Oxide, SrO.—The single published determination [26, 63] of strontium oxide gives the length of the edge of the unit cube: $a = 5.104 \pm 0.01$A.U.

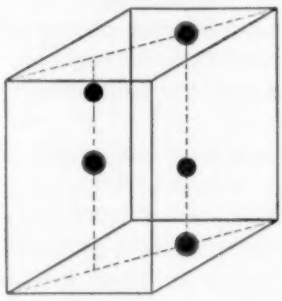
Barium Oxide, BaO.—The two determinations [26, 63] of the side of the unit cube give: $a = 5.47$A.U. and 5.50 ± 0.02A.U.

Zinc Oxide, ZnO.—Diffraction data have been collected by all three of the methods now available. An assignment of structure was made upon the basis of the first (spectrometric) measurements.[34, 72] It appears early to have been indicated [73] (the original papers are not available), and since has been shown,[74] that these spectrometric data do not satisfactorily establish the assigned structure as the only possible one. In the endeavor to distinguish between the different structures that remain possibilities in the light of the spectrometer measurements, Laue [74] and powder [70] photographs [75] have been examined with the help of the results of the theory of space-groups. This latter investigation is one of the best that have been made of any crystal. It is shown that neither the spectrometric observations nor the Laue photographic data are able to decide conclusively between the two arrangements listed below though they favor somewhat the particular arrangement (see I below), which the spectrometer results were supposed to have established. The powder data likewise are in somewhat better agreement with arrangement I. The length of the side of the unit hexagonal prism containing two molecules is determined as: $a = 3.22$A.U., its height $c = 5.18$A.U., corresponding to the axial ratio $c : a = 1.608$. The two arrangements that remain possibilities have the following coördinate positions:

Possibility I:	Zinc:	$\frac{1}{3},\frac{2}{3},0$; $\frac{2}{3},\frac{1}{3},\frac{1}{2}$ (u is here taken as 0)
	Oxygen:	$\frac{1}{3},\frac{2}{3},u$; $\frac{2}{3},\frac{1}{3},u+\frac{1}{2}$.
Possibility II:	Zinc:	$\frac{1}{3},\frac{2}{3},0$; $\frac{2}{3},\frac{1}{3},\frac{1}{2}$. ($u$ is here taken as 0)
	Oxygen:	$00u$; $0,0,u+\frac{1}{2}$.

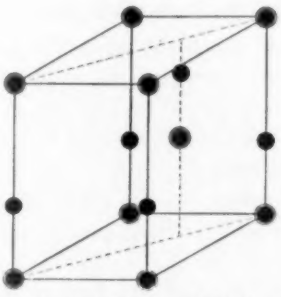
For both arrangements the data are best fitted by a value of u around 5/8, but the experiments are not able to place it with accuracy. The unit cell of I, which is to be taken as the prob-

FIG. 7*a*.



The hexagonal unit of the "zinc oxide arrangement." The positions of the oxygen atoms within the unit are indicated by the black circles.

FIG. 7*b*.



This is the same atomic arrangement as 7*a* with the origin of coördinates shifted to the point (⅓, ⅔, 0) of the previous figure.

ably correct arrangement, is shown in Fig. 7*a*, while the unit cell of Fig. 7*b* is the same distribution with the origin shifted to the point (1/3, 2/3, 0) of the first set of coördinates in order to make it agree in appearance with that previously shown.

This is an excellent example of the insufficiency of methods of crystal structure study which do not make use of the theory of space-groups.

Cadmium Oxide, CdO.—Two determinations[66, 76] of the structure of cadmium oxide, both with powder photographs, give

it the " sodium chloride arrangement " (Fig. 6). The length of the edge of the unit cube is stated as 4.72A.U. Data are given for only one [76] determination.

Nickel Oxide, NiO.—Statements [66, 71] of the structure of nickel oxide as that of the " sodium chloride arrangement " place the length of the side of the unit cell as 4.20A.U. and 4.14A.U. In neither case have any data been furnished. Unanalyzed powder data [70] also have been published.

Cobalt Oxide, CoO.—Powder photographic data which have been published [70] without their having been worked over for the determination of structure are said to agree with the " sodium chloride arrangement."

DIOXIDES.—Attempts have been made to determine the structures of the following dioxides: SiO_2 as quartz; TiO_2 as rutile and as anatase; $ZrSiO_4$ as zircon; SnO_2 as cassiterite and $ThSiO_4$ as thorite. Quartz has trigonal symmetry, the rest are tetragonal, and any discussion which does not treat in detail the many arrangements which become possible in the light of this lower symmetry can have little claim to definiteness. For this reason alone the structures of none of these crystals can be considered as determined even with some degree of probability.

Quartz, SiO_2.—On the basis of some spectrometric observations [35] an atomic arrangement for quartz has been proposed which is built upon a hexagonal unit of structure. From the same data an arrangement has been presented [77] which places the silicon atoms upon a rhombohedral lattice. As determinations of the structure of quartz, either one of these discussions is so totally inadequate that there is no justification for detailed treatment. Much more work, both in the collection of data and in their interpretation, must be carried out before we will have any real indication of the manner of arrangement of the atoms in quartz.

Rutile, TiO_2.—Only spectrometric data are available for the determination of the atomic arrangement in either rutile or anatase. Two investigations have been made upon rutile which do not agree in the data [9, 79] found and which consequently assign to it different structures. The later [79] of the studies gives it a structure which is almost unbelievably complicated. Not only the experimental information but the treatment to which these data have been subjected are incapable of establishing the correct structure for this crystal.

Anatase, TiO_2.—One investigation [80] has been made upon crystals of anatase in which also the data and treatment are incapable of establishing its structure.

Zircon, $ZrSiO_4$.—The studies [9] upon zircon are of the same character and apparently of the same value as those upon anatase.

Cassiterite, SnO_2.—The investigations [9, 79] on cassiterite parallel those upon rutile, though somewhat more fragmentary. Powder data [70] have been published but with no attempt to establish its structure.

Thorite, $ThSiO_4$.—Thorite [9] is commonly found in an altered condition and it is therefore not surprising that the specimens studied could not be made to furnish spectrometric reflections.

TRIOXIDES.—Reflections [81] have been made from a few faces of hematite (Fe_2O_3) and of ruby (Al_2O_3). On the basis of these measurements they have been assigned a structure which resembles that of calcite. The data and the determinations based upon them are not, however, in any sense sufficient for establishing this arrangement and its discussion is not justified. Measurements of dimensions of a unit cell based upon powder photographs have been recorded though no data accompany this statement. Unanalyzed powder data [70] also have appeared.

HYDROXIDES.

Manganese and magnesium hydroxides are the only members of this group whose structures have been studied. They occur as the trigonal minerals, pyrochroite and brucite. Laue photographs have been prepared and their structures deduced with some use of the results of the theory of space-groups. Powder data have also been prepared from precipitated $Mg(OH)_2$ and have been shown to agree with the atomic arrangement for brucite.

Pyrochroite, $Mn(OH)_2$.—This structure [82] was deduced entirely from Laue photographic data. The unit cell developed from the lattice Γ_h contains one chemical molecule and is calculated to have the dimensions: $a = 3.34$A.U., $c = 4.68$A.U. ($c : a = 1.40$). The arrangement of the atoms within this unit cell (Fig. 8) is expressed by the coördinates:

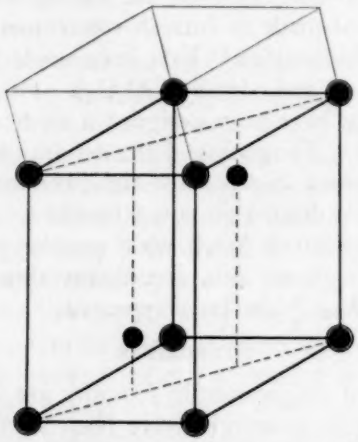
Manganese:	000.
Oxygen:	$\frac{1}{3},\frac{2}{3},u$; $\frac{2}{3},\frac{1}{3},\bar{u}$.
Hydrogen:	$\frac{1}{3},\frac{2}{3},v$; $\frac{2}{3},\frac{1}{3},\bar{v}$.

From a consideration of Laue photographic data it is shown that

u cannot have a value greater than 0.833 nor less than 0.75. The best fit was found for a value of $u = 7/9 = 0.778$ if the usual scattering assumptions are made. The parameter v (for hydrogen) is indeterminable.

Brucite, $Mg(OH)_2$.—In the arrangement of its atoms brucite [82] is strictly isomorphous with $Mn(OH)_2$; the axial ratio is, however, $c : a = 1.5208$. The calculated dimensions of the unit (Fig. 8) containing a single molecule thus become: $a = 3.13$ A.U. and $c = 4.75$ A.U. It is considered that the parameter for

FIG. 8.



The hexagonal unit cell of the "pyrochroite, $Mn(OH)_2$, arrangement." The oxygen atoms are indicated by black circles; the hydrogen atoms are not shown because the positions are indeterminable but they must lie somewhere upon the same vertical lines of the figure as the oxygen atoms. In cadmium iodide iodine atoms are represented by the black circles.

oxygen has the same value as in pyrochroite. Powder photographic data [83] from precipitated $Mg(OH)_2$ are in agreement with this structure, but they are incapable of furnishing satisfactory data for even approximately placing the oxygen atoms.

(To be continued.)

THE INFLUENCE OF STIRRING ON THE RATE AND COURSE OF DEVELOPMENT.*

BY

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THE importance of stirring on development as influencing uniformity has been the subject of frequent comment and not a few definite investigations. Some of the more noteworthy of these are referred to below.[1] In most cases the object of these has been simply to reduce lack of uniformity to a minimum, by suitable mechanical and other precautions, without much inquiry as to what phases of the process allowed such an influence. The work described in the following was undertaken as part of a general investigation of the dynamics of development, and with the particular purposes of ascertaining:

1. Dependence of the mechanical factors on nature of the developing agent;

2. How the mechanical factors may affect uniformity.

EXPERIMENTAL.

In the investigations of Sheppard and Mees [2] on the development dynamics, using plate slips, the slips placed back to back, were rotated in pairs vertically in tubes containing the developer. While this method has been found fairly satisfactory in a large body of sensitometric and kindred investigations, our own examination has shown that the method was not free from error in the matter of uniformity, and that this again was sensitive to the rate of stirring. Recently [3] a very detailed investigation has been made by T. Otashiro of the deviations from uniformity of development with this mode of operation, but using a much

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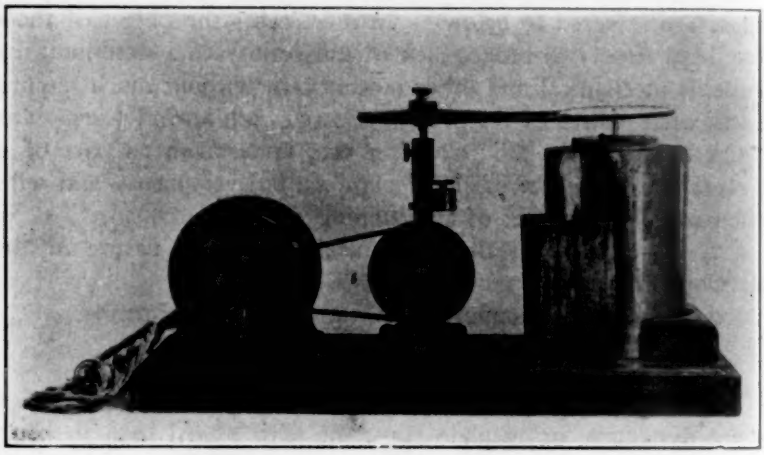
[1] A. Caillier: *Phot. J.*, **53**, 242 (1913); F. F. Renwick, *ibid.*, **52**, 254 (1912); O. Bloch, *ibid.*, **61**, 425 (1921).

[2] "Investigations on the Theory of the Photographic Process," 1907 (Longmans, Green and Co.):

[3] *Bull. Kirya Tech. College* (Japan), May, 1921.

larger plateholder (*viz.*, about 13 cms. wide by 21 cms.)[4] From this it is concluded that "when a dry plate is developed in such a way that it is at first immersed in water, with or without rotation about a vertical axis, and then rotated about the axis in the ferrous oxalate developer, there is a regular difference of the photographic density between the upper and the lower portion, and also between the left-hand side and the right-hand side of the

FIG. 1*a*.



Developing apparatus.

plate, according to the property of the developer and the rotation of the plate in the liquid, though it is uniformly exposed."

Although the conditions in Otashiro's investigation, due to the greater size of the plate, exaggerated the defective uniformity of the vertical rotation method, it is evident that this must exist on a smaller scale. His further conclusion, in favor of vertical development at rest, is satisfactory in this regard, provided no great contrasts of density exist in the plate. Otherwise, as shown by E. R. Bullock[5] the convection currents produced under these conditions are likely to cause trouble.

For the majority of the work on the development process in hand in this Laboratory the use of portrait film has been pre-

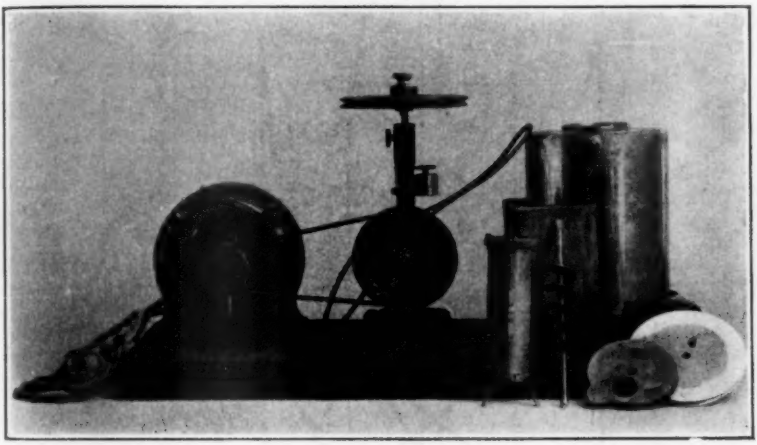
[4] Cabinet size.

[5] *B. J.*, **69**, 110 (1922).

ferred, as giving the most uniform material, particularly in respect to coating. The flexibility of the film support lent itself to the construction of a drum type of developing vessel, in which:

1. Several sensitometric strips $3\frac{1}{4}'' \times 1''$ could be developed simultaneously.
2. The rate of stirring could be varied over a considerable range.

FIG. 1*b*.



Developing apparatus: assembly.

3. Uniform stirring of the liquid relative to the developing surface could be secured at practically all speeds of stirring.

This apparatus enabled us, therefore, to investigate for itself the mechanical factor in development as primarily *velocity of flow of developing solution* over the gelatin surface, largely uncomplicated by secondary effects of the velocity-potential of the flow, such as eddies, accelerations and decelerations, inequalities of velocity, etc.

The apparatus, a photograph of which is shown in Figs. 1*a* and 1*b* and a diagram in Fig. 2, consists essentially of a removable central draft-tube, forming the drum on which the film slips are wound preparatory to development. This drum fits down in the cylindrical developing tube or vessel; the screw agitator is placed inside the draft tube, then developer poured in, the cover and

pulley slipped on, and rotation started. This procedure was found on the whole to give the least initial delay, about five seconds elapsing between immersion in the developer and the commencement of rotation.

The developing chamber, as will be seen from the photograph,

FIG. 2.

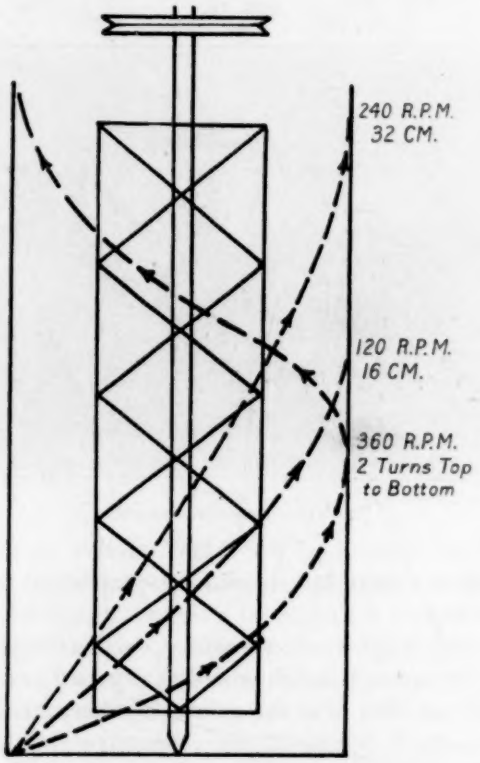


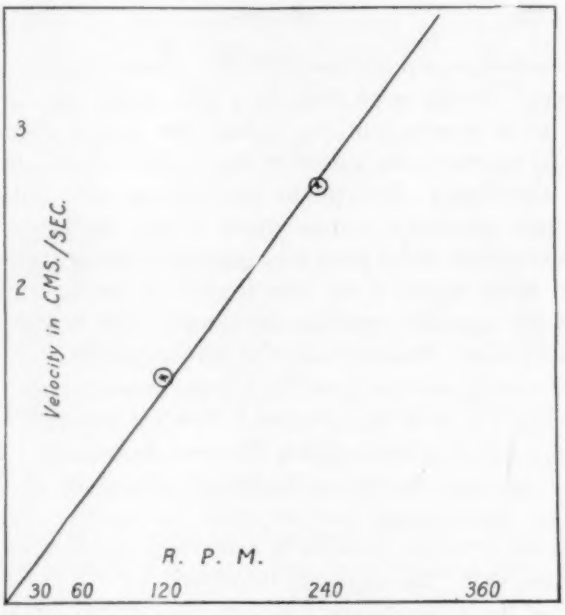
Diagram of developing apparatus showing circulation at different speeds.

is jacketed, and water at constant temperature is circulated through the jacket from a thermostat.

Character of the Motion.—The relation between the stirring velocity and the motion was analyzed as follows: A special counter on the shaft of the agitator enabled the r.p.m. to be determined. The apparatus was assembled with a glass container of

the same dimensions in place of the regular metal developing vessel, and the speed of motion of the fluid observed by following the movement of small pieces of cotton, and by the rate of distribution of drops of dye solution admitted when definite rates of rotation had been installed. The values were as follows:

FIG. 3.



Velocity of Cotton Particles.

R.P.M.	Time.	Distance.	Velocity cms. per sec.	
120	11.5 secs.	15 cms.	1.3	
240	5 secs.	14 cms.	2.8	2.6
	14 secs.	32 cms.	2.3	
360	14 secs.	56 cms.	4.0	

These results show that the velocity is sensibly proportional to the r.p.m. (see Fig. 3) and give figures for the rate at which the solution is renewed at the surface of the film. At the same time, the path of a particle of the liquid alters its character, in the sense that it travels over a helix of lower pitch and greater frequency as the r.p.m. increase. (See Fig. 2.)

To test the question of general equalization, drops of concen-

trated dye solution were inserted and the time for uniform distribution observed.

Velocity of Attaining Uniform Concentration.

R.P.M.	Time of Equalization.	Relative Velocity.
496	6. secs.	.167
260	10.5 secs.	.095
174	16.0 secs.	.062

These results again showed that the velocity was proportional to the r.p.m. At the same time, they give some idea of the time required, at a given r.p.m., to reduce the excess concentration of a soluble reaction component at the surface of the emulsion to uniform distribution throughout the volume of solution used. These results show that improvement in the mechanism is possible, and to secure this a planetary gearing is being introduced by which the drum carrying the film instead of being stationary is rotated in the opposite sense to the screw. The results reported in this paper were obtained with the simpler type.

The film strips were exposed in a Jones non-intermittent sensitometer [6] fixed in acid hypo, washed, dried at constant humidity, and the densities measured with a Martens photometer. Densities including fog were plotted as functions of log E, in the usual manner for constructing the characteristic curves. From occasions of space, it is not possible to reproduce tables and curves of the complete data; the methods developed by A. H. Nietz [7] of determining the convergence point in case of retarded development, and the gamma-time curve were employed. We give as exemplary the following characteristic curves for the course of development at different velocities of stirring for a *hydroquinone: sodium carbonate* developer, which showed the greatest anomaly of those developers examined. (See Figs. 4, 5 and 6.)

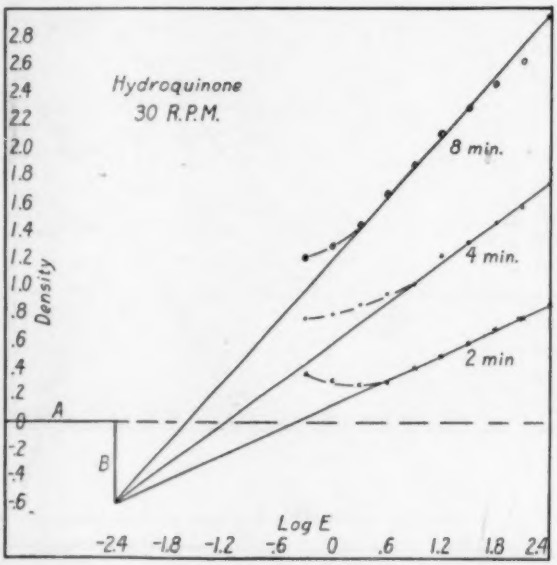
It will be seen from these that the principal change with increased stirring velocity is not a change in *gamma* (see later) but a shift in the position of the convergence point of the straight line portions of the D, log E curves. This corresponds to the

[6] *Phot. J.*, **40**, 80 (1920).

[7] *Phot. J.*, **60**, 280 (1920). A more complete account in press as Monograph 3 on Theory of Photography from the Research Laboratory of the Eastman Kodak Company.

behavior of plates in a developer to which bromide has been added, or containing bromide, or, generally, to what has been termed "retarded development." [8]

FIG. 4.



In the case considered development for different times is yielding a family of straight lines meeting in a point, the coördinates of which are:

a—abscissa in log E units;

b—ordinates in density units,

so that the equation of the curve is

$$D = \gamma(\log E - a) + b$$

which becomes identical with the normal equation $D = \gamma$ (log E – log i) when $b = 0$. The criterion for the intersection of the straight lines is that D is a linear function of γ, *i.e.*,

$$D = \theta(\gamma - a).$$

Examining the action of bromide, Nietz found that a is independent of the bromide concentration, b increases negatively as the bromide concentration is increased.

[8] S. E. Sheppard: *J. Chem. Soc.*, **89**, I. 530 (1906).

FIG. 5.

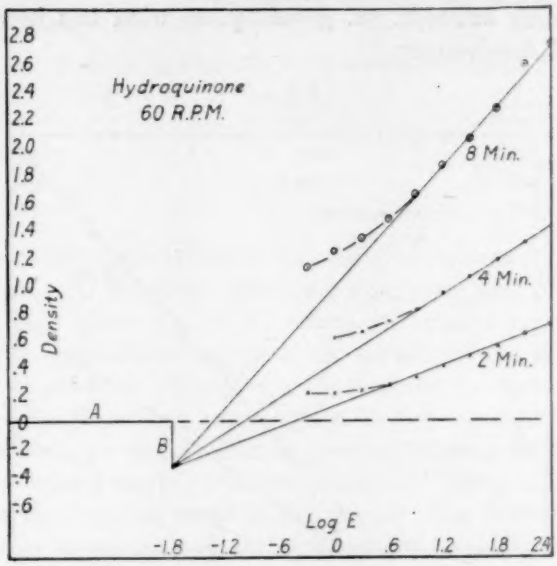
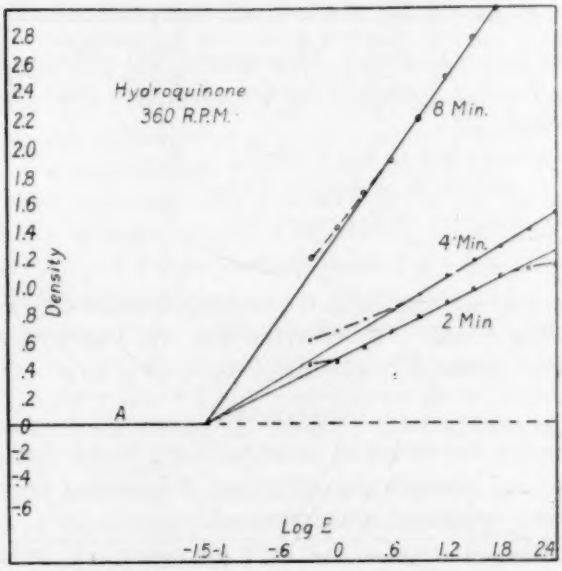
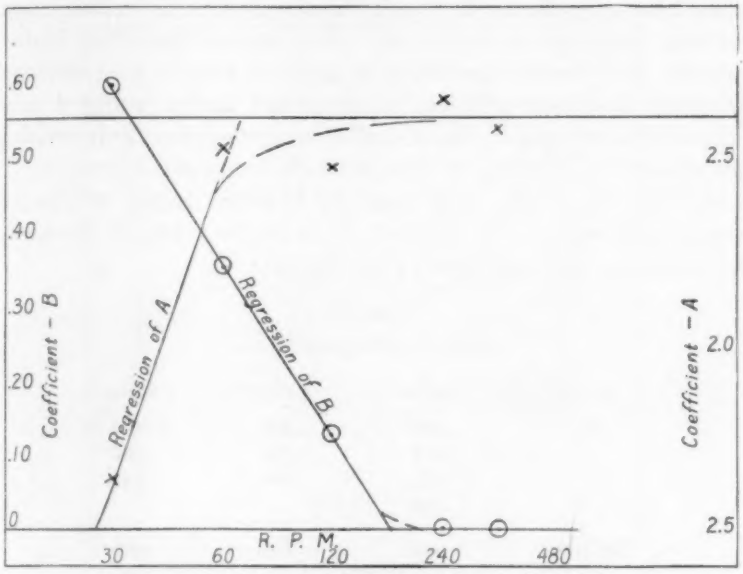

Hydroquinone
60 R.P.M.
8 Min.
4 Min.
2 Min.
Density
Log E
A
B
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-.2
-.4
-.6
-1.8
-1.2
-.6
0
.6
1.2
1.8
2.4

FIG. 6.


Hydroquinone
360 R.P.M.
8 Min.
4 Min.
2 Min
Density
Log E
A
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-2
-4
-6
-1.5-1
-.6
0
.6
1.2
1.8
2.4

The values of a and b for the developers used were tabulated for different velocities, as also the values of γ_t the development coefficient for time t.

FIG. 7.



Regression phenomena hydroquinone-carbonate developer.

TABLE I.

Developer				
Hydroquinone		5.5 gms. = 1/10 molar		
Na_2SO_3		50 gms.		
Na_2CO_3		59 gms.		
With water to		1000 c.c.		
	R.P.M.	Velocity	a	b
Series i	30	.32	−2.40	0.60
ii			−2.35	0.70
iii			−2.35	0.51
Series i	60	.65	−1.32	0.40
ii			−1.32	0.30
iii			−1.80	0.36
Series i	120	1.3	−1.71	0.15
ii			−1.35	0.10
Series i	240	2.6	−1.35	0.00
ii			−1.35	0.00
iii			−1.35	0.00
Series i	360	4.0	−1.46	0.00
ii			−1.41	0.00

We have plotted these values of a and b as functions of the logarithms of r.p.m., *i.e.*, of velocities of stirring. It will be seen from the table and the curves (Fig. 7), that while there is some shift in the absolute value of a it soon attains a constant value, while b steadily diminishes with increasing stirring velocity, and becomes negligible at 240 r.p.m. This means that while hydroquinone with sodium carbonate is liable to behave as a retarded developer (without addition of bromide) under ordinary conditions of development, this retardation is overcome by increasing the velocity of stirring, so that it tends to behave normally. It is obvious that at the same time the Watkins factor will be increased somewhat. The relation of γ_t to the r.p.m. is shown in the following table and figure (see Fig. 8):

TABLE II.

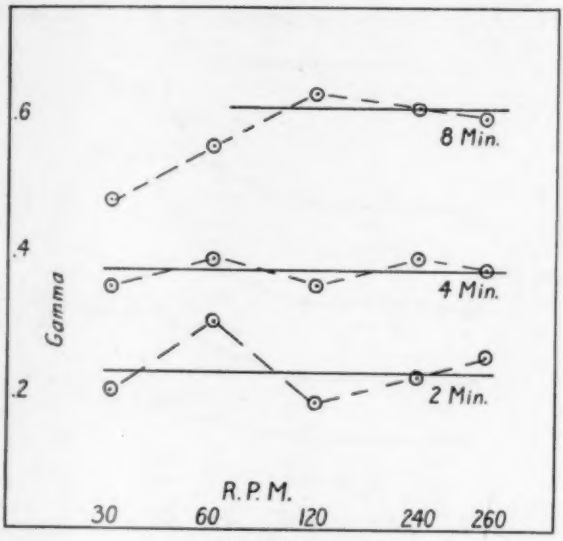
Hydroquinone-carbonate.

R.P.M.	γ 2 mins.	γ 4 mins.	γ 8 mins.
30	.204	.324	.480
	.155	.255	.382
	.154	.480	.532
	.300		
Average	.200	.353	.465
60	.353	.280	.487
	.380	.437	.486
	.310	.435	.690
Average	.304	.384	.554
120	.211	.340	.582
	.145	.395	.700
			.610
Average	.180	.368	.630
240	.160	.453	.600
	.295	.405	.680
	.206	.320	.580
Average	.220	.393	.620
360	.279	.500	.596
	.214	.270	.582
Average	.246	.385	.589

It will be seen that up to four minutes there is no definite variation of γ with rate of stirring; at six minutes there is indi-

cation of some increase of γ up to 120 r.p.m., after which it remains independent of the velocity. Before considering any explanation of these results, we will give the data for other developers examined.

FIG. 8.



Hydroquinone.

TABLE III.
Pyrogallol.

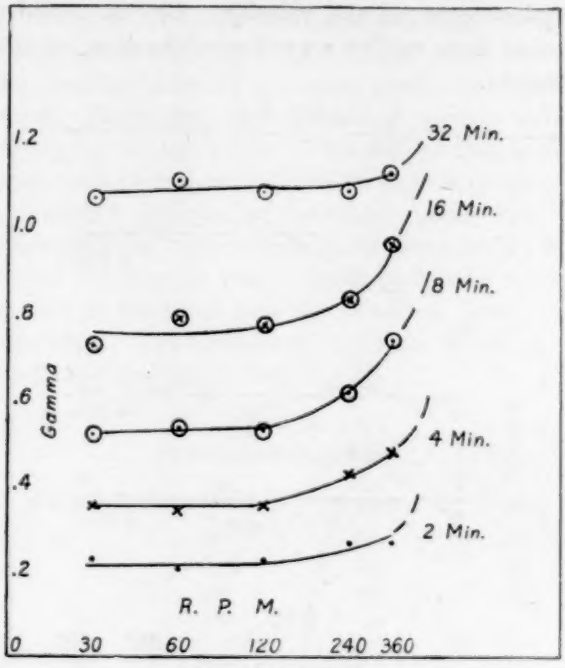
Standard Formula

Pyrogallol	6.3 gms. = 1/20 molar
Na_2SO_3	50 gms.
Na_2CO_3	50 gms.
Water to	1000 c.c.

R.P.M.	Velocity.	a	b
30	.32	−1.30	0.10
60	.65	−1.30	0.00
120	1.30	−1.30	0.00
240	2.60	−1.30	0.00
360	4.00	−1.30	0.00

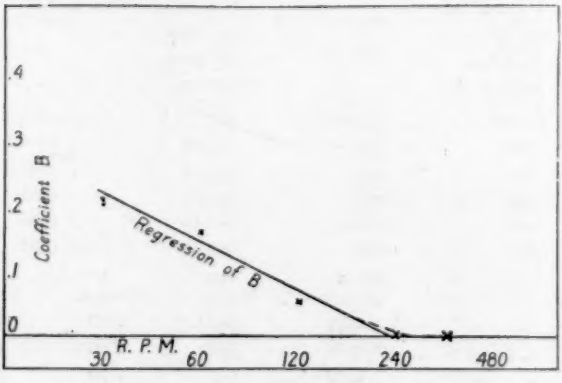
R.P.M.	γ 2 mins.	γ 4 mins.	γ 8 mins.	γ 16 mins.	γ 32 mins.
30	.225	.355	.515	.720	1.060
60	.202	.338	.532	.800	1.100
120	.226	.350	.525	.770	1.075
240	.265	.425	.612	.825	1.078
360	.267	.475	.738	.955	1.113

FIG. 9.



Pyrogallol standard.

FIG. 10.

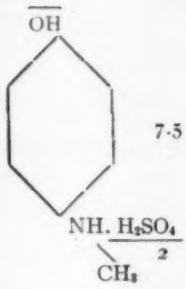


Elon.

Regression effect in *elon* developer.

TABLE IV.

Elon



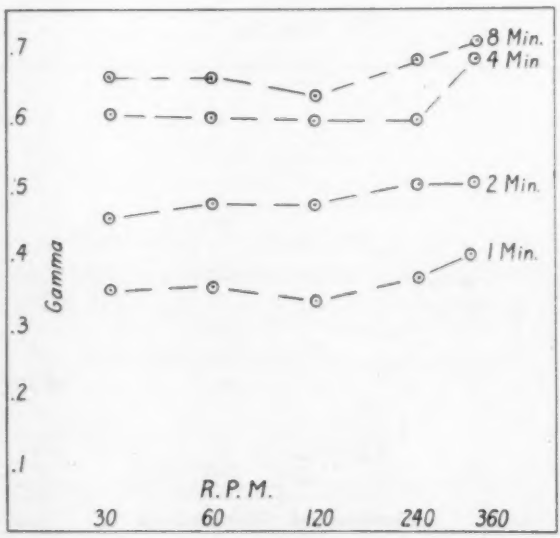
Elon 7.5 gms. = 1/20 molar

Na_2SO_3	50 gms.
Na_2CO_3	50 gms.
Water to	1000 c.c.

R.P.M.	Velocity.	a	b
30	.32	−1.23	.29
60	.65	−1.27	.37
120	1.30	−1.23	.10
240	2.60	−1.20	.06
360	4.00	−1.20	.10

R.P.M.	γ 1 min.	γ 2 mins.	γ 4 mins.	γ 8 mins.
30	.340	.460	.600	.650
60	.365	.475	.590	.660
120	.330	.470	.592	.630
240	.368	.500	.590	.670
360	.410	.500	.680	.710

FIG. 11.



Elon.

TABLE V.

Experiment 224. P-amino-phenol.

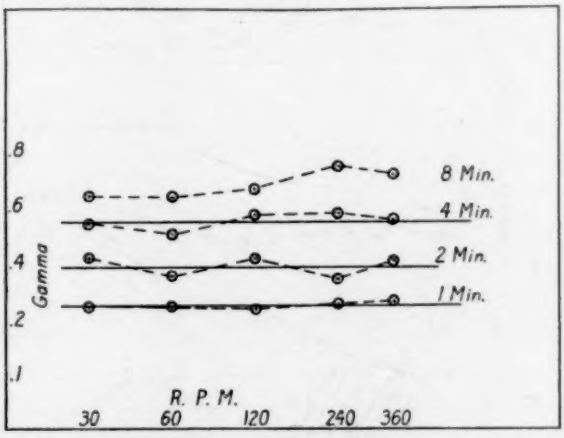
p-amino-phenol hydrochloride

7.275 gms. = 1/20 molar

R.P.M.	Velocity.	a	b
30	.32	−1.04	0.21
60	.65	−1.05	0.16
120	1.30	−1.05	0.05
240	2.60	−1.05	0.00
360	4.00	−1.05	0.00

R.P.M.	γ 1 min.	γ 2 mins.	γ 4 mins.	γ 8 mins.
30	.240	.412	.538	.631
60	.232	.346	.493	.626
120	.227	.411	.562	.660
240	.247	.335	.571	.740
360	.260	.403	.548	.710

FIG. 12.



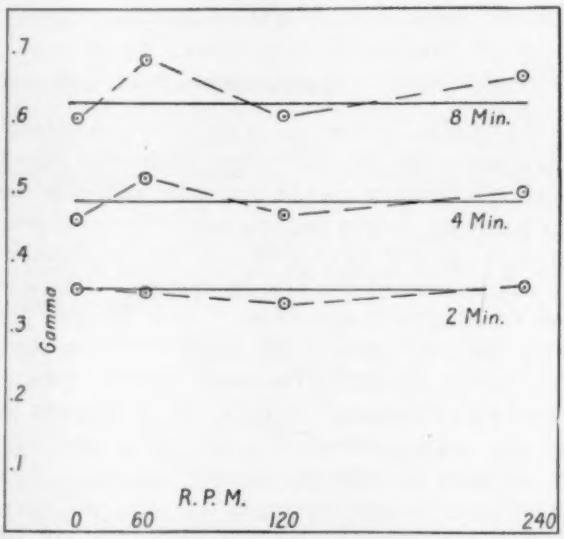
P-amino-phenol. Experiment 224.

Experiment 227 p-amino-phenol 7.275 gms. = 1/20 molar.

R.P.M.	Velocity.	a	b
30	.32	−1.21	0.20
60	.65	−1.16	0.07
120	1.30	−1.20	0.005
240	2.60	−1.20	0.00
360	4.00	−1.20	0.00

R.P.M.	γ 2 mins.	γ 4 mins.	γ 8 mins.
30	.339	.454	.587
60	.338	.517	.686
120	.328	.457	.590
240	.361	.492	.628

FIG. 13.



P-amino-phenol. Experiment 227.

Finally, an experiment was made with a (pyro) developer containing free bromide. This was made with a different batch of emulsion, hence different value of coefficient a.

TABLE VI.

R.P.M.	Velocity.	a	b
30	.32	−0.8	.51
60	.65	−0.8	.45
120	1.30	−0.8	.52
240	2.60	−0.8	.50
360	4.00	−0.8	.50

R.P.M.	γ 1 min.	γ 2 mins.	γ 4 mins.	γ 8 mins.	γ 16 mins.	γ 32 mins.
30	.26	.44	.69	1.08	1.10	1.15
60	.21	.38	.61	.85	1.14	1.20
120	.18	.41	.63	.92	1.06	1.20
240	.19	.42	.63	.89	1.17	1.27
360	.15	.33	.57	.90	1.03	1.15
	.20	.40	.63	.93	1.10	1.195

The formula for this developer was as follows:

Pyro	5 grams
$K_2S_2O_5$	4.4 grams
Na_2SO_3	16.0 grams
Na_2CO_3	18.7 grams
KBr	0.25 grams
Water to	1 litre

CONCLUSIONS.

From the results obtained from the very considerable amount of data, it appears that the following conclusions may be drawn, though some qualification may be necessary with other emulsions.[9] It appears generally, within the limits of velocity of stirring used, that the rate of growth of gamma, *i.e.*, the *development velocity*, is largely independent of the rate of stirring. This confirms the conclusion of Sheppard and Mees [10] with ferrous oxalate that "increasing the rotation had but slight effect on the velocity." While this appears generally true, there appears to be a tendency, notably with *pyro* (standard formula) and to a lesser extent with *elon*, for the higher velocities—240 r.p.m. and upwards—to definitely increase the velocity of development. Although the velocities of flow in question—over 2.5 cms. per sec.—are outside ordinary photographic practice, they are not beyond the conditions in continuous development of motion picture film, for which a normal velocity of movement is already 1800 feet/hour = 15 cms. per second. We expect to investigate the effects at these and higher velocities in continuation of the present work. It appears possible that at these higher velocities of stirring some of the complications of the velocity-function of development [11]

[9] The emulsion used was one which independent grain-size analysis [cf. E. P. Wightman and S. E. Sheppard, *J. Phys. Chem.*, **25**, 561 (1921)] showed to have a wide range of grain sizes, hence it is likely to be fairly representative.

[10] *Op. cit.*, p. 58.

[11] Cf. A. H. Nietz, *loc. cit.*

may be considerably reduced. This view is supported by consideration of the influence of stirring velocity upon the coefficients a and b of the family of characteristic curves. It will be seen that with hydroquinone-sodium carbonate, a developer of very low reduction potential, there is a progressive change of both a and b with increased velocity of flow. The coefficient a rapidly attains a constant value independent of the velocity of flow, but the b coefficient shows a more prolonged regression. In Fig. 7 the values of a and b have been plotted against the logarithms of the velocities of flow (or r.p.m.). Of the other developers investigated, *pyrogallol* showed only a very slight regression of b, while *p-amino-phenol* and *elon* show it slightly more.

Provisionally we consider that this effect is a consequence of increased removal of soluble bromide, formed during development, from the emulsion layer. The more pronounced and definite effect with hydroquinone carbonate is in agreement with this view. Nietz has found that the value of $-b = d$, the depression of the convergence point due to bromide is given by $-b = m(\log C - \log C_o)$ where m is a constant, C is the concentration of bromide, C_o the concentration only just producing a depression. On the washing-out hypothesis, the concentration of bromide in the film would be approximately

$$C = n.\left(\frac{1}{V} - \frac{1}{V_o}\right)$$

where V is the velocity of stirring. Now b was found to fall off approximately as the logarithm of the stirring velocity, which is therefore in agreement with the view that the bromide in the film is the cause of the effect, which becomes practically negligible when the relatively small amount is washed out as formed and distributed through the whole solution. The only objection to this hypothesis appears to be the following. The normal bromide effect is a consequence of a uniform amount of bromide, independent of the amount of developing image. Under the conditions considered here, the bromide, being formed locally in proportion to the silver developed, might be expected to have a different influence, not shown by a steady definite depression b of the density. However, in the case of hydroquinone carbonate, there was actually a shift of a, which is not found with the normal bromide effect, and this may be due to the circumstance just noted. The

explanation offered seems the simplest and most probable, in view of our present knowledge of the dynamics of development.

Finally, it may be noted that the effects observed, particularly when intensified by other factors, such as developer exhaustion, etc., account for part of the anomalies sometimes encountered by workers in photographic sensitometry.

SUMMARY.

1. An apparatus is described for uniform development of sensitometric strips on film at various velocities of stirring (30 to 400 r.p.m.).

2. Results obtained with hydroquinone, pyrogallol, p-aminophenol, and elon developers are given in tables and graphically.

3. It is found that the velocity of development, as rate of growth of γ, is little affected by rates of flow up to 4 cms. per second.

4. With hydroquinone carbonate at low stirring velocity an effect like bromide depression (induction) was observed; this is removed as the stirring velocity is increased. The effect (induction) with other developers used was small or negligible.

5. This regression is attributed to improved removal of soluble bromide from the film with increased velocity of stirring.

Heavy Fuel Oils in Internal Combustion Engines.—This problem is the subject of a paper recently read by Harold Moore, M.Sc., before the North-East Coast Institution of Engineers and Shipbuilders, at Newcastle-on-Tyne.

The difficulties in burning heavy oil are of three types: Ignition, burning after ignition, impurities. These types are distinct. Oils may be found satisfactory in two respects, but unfit for use on account of the other defect. Heavy-oil engines are classified by the author in three groups: Diesel engines, using compressed air for firing; cold-starting engines which fire by spontaneous combustion, the fuel being pulverized without air blast; hot-bulb engines, in which the fuel is injected mechanically, external heat being applied to ensure ignition. The capacity of an engine for burning heavy fuels is not merely dependent upon the cycle and method of fuel injection; it is also dependent to a very marked extent upon the size, speed, compression, fuel-valve tuning and other factors.

The chemistry and physics of the difficulties are presented in much detail and remedies are pointed out. The paper is quite extensive and covers a subject of great importance on power industry. H. L.

RESISTIVITY OF VITREOUS MATERIALS.*

BY

L. L. HOLLADAY,

Physicist, Laboratory of Applied Science, Nela Research Laboratories.

ABOUT a year ago the writer investigated the resistivity of various types of glasses and found that all the results seemed to follow a general law, which apparently had not been heretofore recognized.

It is well known that the resistivities of glasses and other similar substances are high at room temperatures and that they decrease greatly as temperatures near their softening points are approached. Indeed the changes are so great that the resistivities are frequently expressed and plotted logarithmically.

In making our tests upon the resistivity of glass, several methods of test were made necessary by the fact that the range of resistivity values cold and hot were in about the ratio of 10^{13} to one. All our measurements were made upon glass tubes about one-half inch outside diameter. At temperatures from 20° to 75° C. measurements were taken with the current traversing the walls of the tube radially by sealing one end of the tube and placing it in a conducting bath, and filling it with some of this same liquid. The current through the glass was measured with a very sensitive galvanometer.

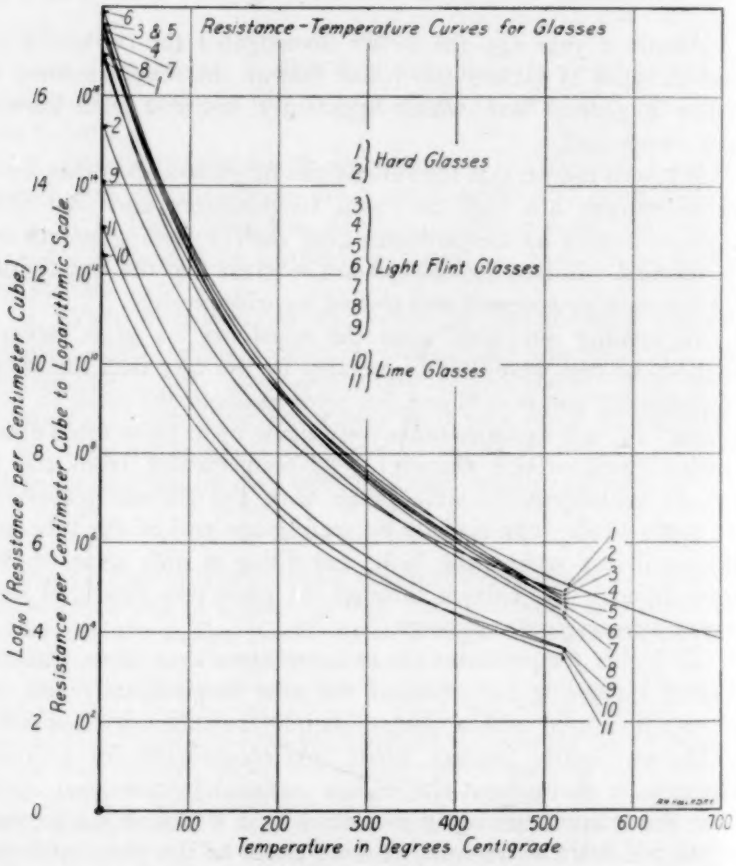
At higher temperatures the measurements were taken with the current traversing the walls of the tube longitudinally and the current measured with a potentiometer; the tube was suspended within an electric furnace which was constructed for uniform temperature throughout the region occupied by the glass specimen, the temperature being measured by a standardized thermocouple. Electrical connections were made to the glass specimen first by electroplating a band of copper around each end; and later, by fusing wires, having about the same coefficient of expansion as glass, into the ends of the tube.

During this investigation eleven specimens of glass were tested through a temperature range of about 20° to 500° C. and

* Communicated by the Director of the Laboratory.

the results plotted. For each specimen of glass the results were plotted, the logarithm of resistivity being plotted against temperature. Through these points a smooth curve was drawn. Fig. 1 shows a summary plot for the eleven specimens. Were

FIG. 1.



absolute temperature used instead of Centigrade, the curves would be more or less asymplotic to the two axes. When the logarithm of resistivity for a given specimen is plotted against the reciprocal of absolute temperature the curve is practically a straight line which projected intersects the temperature axis close to the origin. A summary plot of these results is given in Fig. 2.

An impirical formula satisfying the experimental results for each specimen was derived, and all were found to be of the following general form

$$\text{Log}_\varepsilon (R) - x \log_\varepsilon (T) = \frac{Q}{T} - \log_\varepsilon (P)$$

The equation for resistivity R may therefore be written

$$R = \frac{T^x}{P} \varepsilon^{\frac{Q}{T}}$$

and the corresponding equation for conductivity is $K = \frac{P}{T^x} \varepsilon^{-\frac{Q}{T}}$

where P, Q, and x are constants, and ε is the base of natural logarithms.

For specimens Nos. 1, 3, 4, 5, 6, 7, and 8 a few more of the points fell below the straight line than above at the ends when the logarithm of resistivity was plotted against the reciprocal of temperature; thus indicating that x had a negative value of about one-half. However, owing to different methods of measuring the resistivity at high and low temperatures and owing to the experimental difficulties of measuring at the two extremes of the temperature range, it is not certain that the curves in these cases are straight lines. Fig. 3 has been prepared to illustrate the slight change in the shape of the curve that is effected by assuming that x is equal to plus or minus one. The three curves pass through the common points corresponding to the temperature of 323° K. and 723° K.

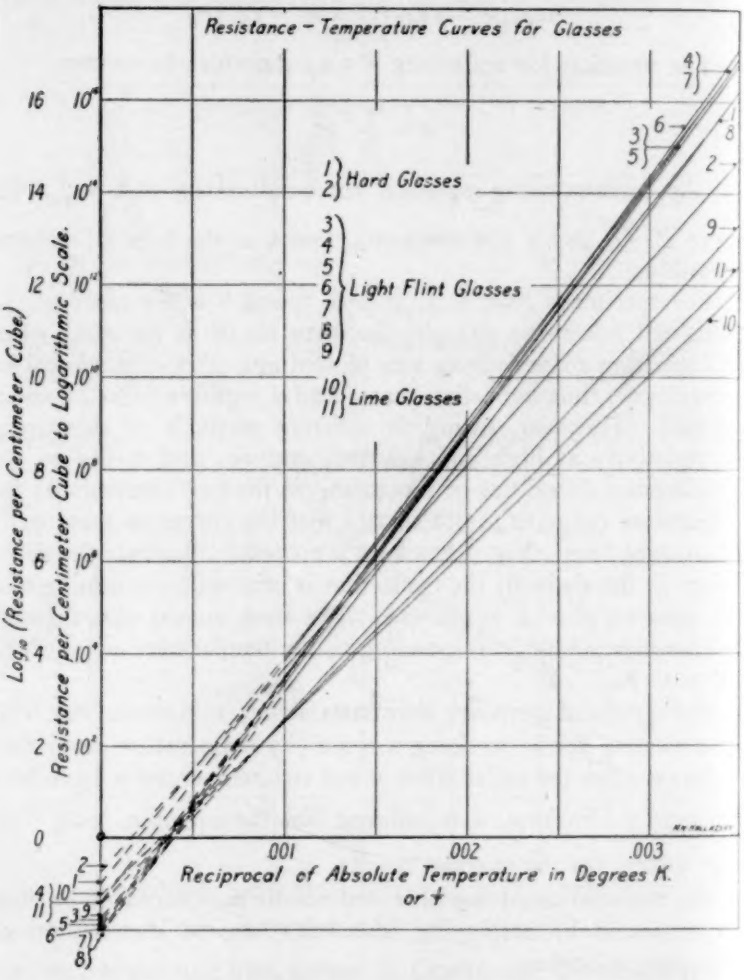
For practical purposes it is satisfactory to assume that x is equal to zero, for by so doing a resistivity-temperature curve may be drawn when the resistivities at but two temperatures have been measured. However, it is believed that the equation $R = \frac{T^{-\frac{1}{2}}}{P} \varepsilon^{\frac{Q}{T}}$ more nearly fits the average results.

An explanation of our observed results may probably be most simply found by employing Maxwell's law of distribution of molecular velocities.

Since glass is an amorphous substance with presumably no crystalline structure, free electrons would probably encounter about the same kind of resistances to their movement that they do in an ordinary gas, and would be acted upon by the electric forces of ionized molecules and other electrons about as in a gas.

As a concrete example of this, J. C. Ghosh[1] showed that in a solution of strong electrolytes the proportion of dissolved

FIG. 2.



molecules which are dissociated and yield free ions for the production of current is $\varepsilon^{-\frac{A}{nRT}}$, where $\frac{A}{nR}$ is proportional to the work expended in removing an ion out of the sphere of influence

[1] *Chem. Soc. J. Trans.*, 113, pp. 449–458, May, 1915.

of neighboring ions. By the application of this formula he was enabled to calculate the conductivity of binary electrolytes to within 1 per cent. of observed values. When we assume that instead of n being the number of ions into which a molecule dissociates, it is the number of electrons and charged molecules formed by the ionization of the glass molecules, and when in addition we assume suitable data for glass we obtain a value for Q of the same order of magnitude as the ones given in the accompanying table calculated from observed data.

Following the striking discoveries of super-conductivity by K. Onnes, O. W. Richardson,[2] by employing the theory of doublets, advanced by J. J. Thomson, gave the conductivity of a metal when its temperature is sufficiently high for the specific heats of the metal to become normal as follows:

$$K = \frac{1}{3}\frac{NepdM}{kT},$$

where N is the number of doublets in unit volume, M the moment of a doublet, e the electronic charge, p the number of times an atom emits an electron per second, d the distance between the centres of adjacent atoms, k Baltzmann's constant, and T the absolute temperature. Also assuming that free electrons obey Maxwell's law of distribution of velocities and other gas laws, he showed that the ratio of the total number of electrons that start to the surface to the number that actually escape is

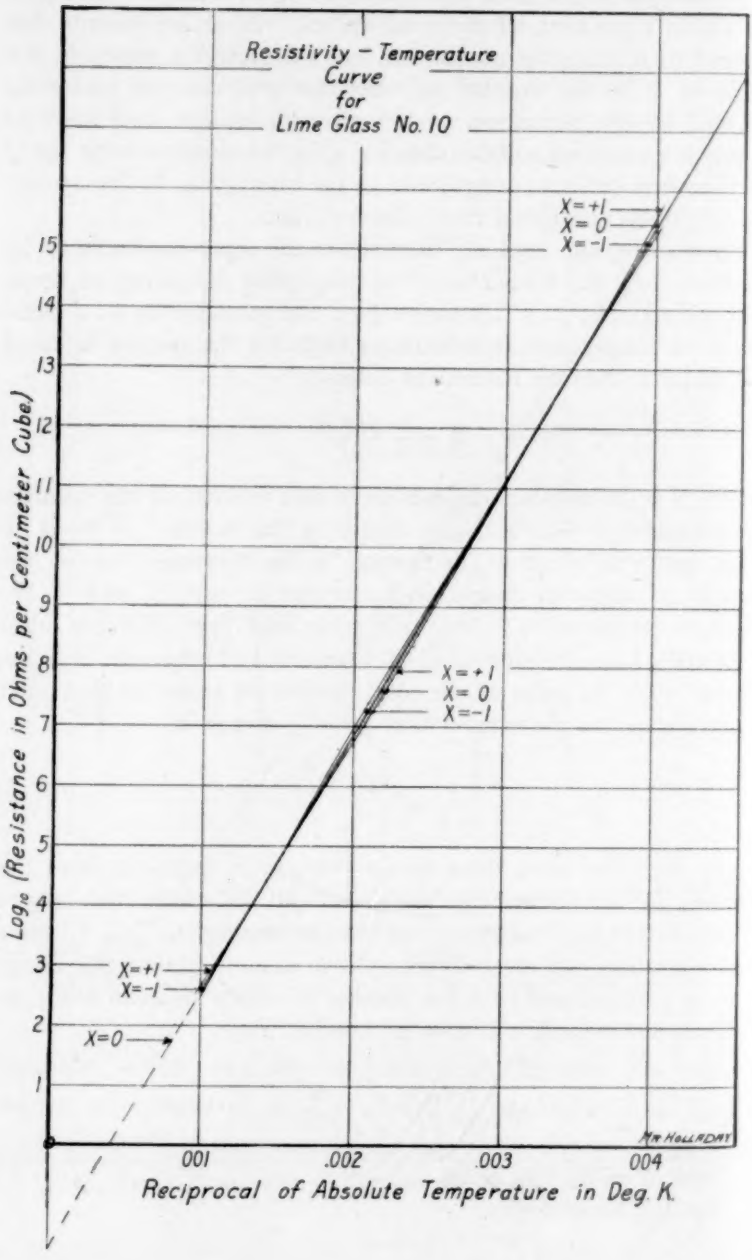
$$\frac{1}{\sqrt{\pi}}\sqrt{\frac{kT}{w}}\,\varepsilon^{-\frac{w}{kT}}$$

where w is the work done by an electron in escaping from the surface. If we assume that the surface be the sphere of influence of other electrons and atoms, we have an analogy to J. C. Ghosh's demonstration for electrolytes. Now assuming that the above ratio is proportional to p the number of times an atom emits an electron per second, we have for conductivity

$$K \alpha \frac{1}{3}\frac{NedM}{kT}\frac{1}{\sqrt{\pi}}\sqrt{\frac{kT}{w}}\,\varepsilon^{-\frac{w}{kT}}$$

[2] *Phil. Mag.*, 30, 1915, p. 295.

FIG. 3.


Resistivity – Temperature
Curve
for
Lime Glass No. 10
X=+1
X=0
X=-1
X=+1
X=0
X=-1
X=+1
X=-1
X=0
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Log10 (Resistance in Ohms per Centimeter Cube)
.001
.002
.003
.004
Reciprocal of Absolute Temperature in Deg. K.
M. H. HOLLADAY

Or assuming that N, d, and M are constant, the expression for conductivity becomes

$$K = \frac{P}{\sqrt{T}} \varepsilon^{-\frac{Q}{T}}$$

On the other hand, if M varies as $T^{-\frac{3}{2}}$, which Richardson states will make it accord with thermodynamical requirements, our equation for conductivity becomes

$$K = \frac{P}{T^2} \varepsilon^{-\frac{Q}{T}}.$$

It is the writer's belief that this equation does not accord with the experimental data as well as the former equation.

In conclusion it may be stated that experimental results show and theory indicates that the conductivity of vitreous substances varies according to absolute temperature T as $\varepsilon^{-\frac{Q}{T}}$. And theory indicates that conductivity may also vary with temperature as $T^{-\frac{1}{2}}$ or as T^{-2}; but throughout the working range of temperature for glasses it is practically immaterial which exponent is employed.

From the observed values of R for several glasses, values of P and Q have been estimated and tabulated below for assumed values of x equal to $+\frac{1}{2}$ and zero.

Type of Glass.	No.	Values of Constants For $X = +\frac{1}{2}$ P	Q	For $X = 0$ P	Q
Hard Glass	1	453	11,630	9.1	11,280
Hard Glass	2	157	10,280	5.7	10,160
Light Flint Glass	3	2,291	12,430	74.1	12,270
Light Flint Glass	5	2,870	12,510	84.1	12,340
Light Flint Glass	7	8,091	12,970	99.5	12,400
Light Flint Glass	9	1,807	10,040	49.	9,790
Lime Glass	10	1,145	9,370	23.7	9,050

Thermal Analysis at Low Temperatures. F. E. E. GERMANN. (*Phys. Rev.*, June, 1922.)—Solutions of uranyl nitrate were heated and cooled between the temperatures of melting ice and of a mixture of ether with solid carbon dioxide. A thermo-electric junction of copper-advance placed in the solution enabled the temperatures of the latter to be followed. The common course of temperature changes was the following: For a brief time the solution fell in

temperature, then it rose for an even shorter time until the whole mass was a solid mixture of ice and uranyl nitrate hexahydrate, $UO_2(NO_3)_2.6H_2O$. After this for a much longer time the temperature grows less. This is succeeded by an interval, when it suddenly rises through a considerable number of degrees. After this there is a continuous fall of temperature. A study of solutions of varying concentration showed that the maximum amount of heat evolved during the second and more important rise of temperature is displayed in a solution containing 48 per cent. of uranyl nitrate. When the specimen, the cooling curve of which was described above, is heated up, the temperature rises to a certain point and then remains almost constant for a time while heat is being absorbed. Subsequently a rise of temperature follows.

These observations are interpreted to indicate that a new hydrate, the icositatrahydrate, $UO_2(NO_3).\ 24H_2O$, is formed at about $-35°$. This decomposes spontaneously at $-20°$.

"When a water solution of uranyl nitrate is cooled to the temperature of liquid aid, it is possible to get a distinct fluorescent spectra from it, depending in general on the rate of cooling. H. L. Howes has described what seemed to him to be five distinct spectra, varying from a sharp line spectra in the case of slow cooling to a broad-banded spectrum in the event that the solution was plunging directly into liquid air. The other spectra were the results of other chance intermediate methods. As far as we know to-day, the emission and absorption spectra of elements and compounds are very characteristic at any given temperature, so that it would seem quite impossible to obtain more than one fluorescent spectrum for a given compound." The inferred existence of the new hydrate goes far to explain how so many spectra can be emitted. G. F. S.

On Reflection from a Moving Mirror and the Michelson-Morley Experiment. E. H. KENNARD and D. E. RICHMOND. (*Phys. Rev.*, June, 1922.)—The results of the celebrated Michelson-Morley experiment are usually interpreted in such a manner that they form the very foundation of the Theory of Relativity. As a consequence of the constantly increasing range of this theory the underlying experiment has been subjected to close scrutiny. Righi has done this and has attacked the common explanation of the results. This is, on the other hand, defended by Villey. The two authors approach the problem afresh. They are particularly concerned with a second-order term which, in Righi's opinion, is adequate to explain why the experiment gave only a negative result. They conclude that this troublesome term would not change to a perceptible extent the pattern of interference fringes. "It appears certain therefore that the famous negative result of Michelson and Morley was not due to any second-order effect of motion upon reflection at the mirrors." "The usual interpretation of the experiment in favor of Relativity still holds." G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

ANNUAL REPORT OF THE DIRECTOR OF THE BUREAU OF STANDARDS, 1922.[1]

[ABSTRACT.]

THE outstanding feature of the fiscal year ended June 30, 1922, as far as the Bureau of Standards of the Department of Commerce is concerned, was the great amount of attention paid to industrial standardization, to the elimination of waste in the industries, and to the simplification of industrial products. While fully as much time and attention has been paid to fundamental measurements as heretofore, these have all been carried out with the particular idea of their importance in some definite line of work. It is gratifying to note that in all the important researches which have been undertaken, the Bureau has had the hearty coöperation of American manufacturers. Their aid has been invaluable in the solution of industrial problems, and it is believed that the cordial relations which now exist between the Bureau and the industries will continue in the future.

The number of tests completed during the year include 62,104 for the Government, 30,464 for the public, representing a value of $345,001.05. The personnel of the Bureau has been made up of 342 statutory employees and 546 engaged in special research.

In connection with weights and measures, a great deal of attention has been paid to the improvement of the apparatus with which such work is conducted. Very satisfactory comparisons were made between the fundamental standards of the Bureau and sets of high precision weights showing that the accuracy of the standards has not been decreased over a long period of time. An important development was the recognition by the Bureau of a special specific gravity scale for the petroleum industry, and the Bureau's agreement to certify apparatus according to this scale.

Very satisfactory progress was made in testing railroad track scales, and a considerable improvement has been noted in their accuracy. The mine scale work, however, was greatly interfered

* Communicated by the Director.

[1] Miscellaneous Publication, No. 50.

with by the strike in that industry. The Fifteenth Annual Conference on Weights and Measures was particularly successful and several notable speakers, including the Secretary of Commerce, took part at the meetings.

In the field of electricity, many important accomplishments may be recorded. The year has been marked by an unprecedented increase of popular interest in radio, and to meet the demand the Bureau has issued a number of publications treating with this subject in a more or less elementary way. It has also aided in the testing of radio apparatus.

An important conference was held at the Bureau at which standard specifications were prepared covering all classes of dry cells. As a result of the adoption of these specifications, the number of sizes of cells which dealers must keep in stock will be greatly reduced.

Investigations to determine better ways for utilizing natural and artificial gas in industrial and domestic appliances have been carried out, and several publications have been issued on this subject.

Quite a change was noted in the type of clinical thermometers submitted for test. During the past year over 90 per cent. of such thermometers were for human use as compared with but 5 per cent. last year. A steady movement may be noted tending toward the rigid testing of all such thermometers which are sold, and it seems probable that the Federal Government will be asked to aid in this work.

Very elaborate investigations covering a long period resulted last year in the preparation of tables giving the thermodynamic properties of ammonia, the most complete work of the sort that has ever been carried out.

In connection with the testing of internal combustion engines, particular attention has been paid to road tests of automobiles and special apparatus has been designed which will give the performance of any type of car under service conditions.

In the field of optics, many important results have been achieved. The Bureau's figures for the length of the cadmium red line as a fundamental standard of wave-length have been adopted by the International Astronomical Union. Measurements have been made of the radiation of a large number of stars using apparatus specially designed by the Bureau.

Close coöperation has continued between the Bureau and the sugar industry, and with the very complete apparatus now in the Bureau's laboratories even more important results may be expected.

During the year special attention has been paid to a study of nickel deposition with the hope that those conditions of operation which will yield the most satisfactory results with the least expense and loss can be defined.

Many different kinds of balloon fabrics have been tested, and a method for showing the purity of gas in a balloon without the necessity of drawing any of the gas from the balloon has been developed.

Important work in coöperation with British, Scotch, and Italian analysts has been carried out on standard pure metals.

Work in connection with the sound transmitting properties of building materials has been continued during the year, and a special sound chamber where such measurements may be carried out has been completed. Also a new and larger wind-tunnel was put in service giving the Bureau exceptionally fine equipment for aerodynamical work. A large number of aeronautic instruments have been tested and designed to meet special requirements, nearly all this work having been conducted in coöperation with the Army and Navy Air Services.

In the field of structural materials, a fundamental investigation is under way on the theory of columns as well as on the fatigue resistance of metals. Other work in progress includes an investigation of the use of concrete for houses and inspection of such structures already in existence.

An endurance testing machine for automobile tires has been completed, and the special apparatus for measuring power loss in tires has been in almost constant use. A publication was issued on the durability of sole leather prepared by two different methods, and in the field of textiles very important work, much of which was of a coöperative character with textile organizations, has been carried out. One of the principal investigations conducted during the year was on the heat-retaining properties of blankets.

Work which will eventually lead to the standardization of paper sizes is well under way, and, as in the case of textiles, important coöperative work along many lines may be recorded.

Important metallurgical investigations have included a study of methods for the analysis of gases in metals, the determination of thermal stresses in car wheels, and the rust resistance of alloy steels. Particularly important work has been accomplished by the research associates in metallurgy sent to the Bureau by various manufacturers.

As in other work, in connection with ceramics the practical problems have been particularly stressed. Tests have been conducted of tableware and window glass, the best types of American clays to use in paper-making have been determined, and the comparative value of various ceramic materials for different purposes has been investigated.

The making of optical glass in the Bureau's laboratory has been carried on very successfully, a great deal of first-class glass in the form of lens blanks and finished lenses having been supplied to other branches of the government, particularly the Navy Department.

Specifications are being prepared for refractories, such as the fire brick in boiler furnaces, and work is under way which will lead to the improvement of enamelled metal products.

New and important work undertaken during the year was that in connection with building and housing, and several publications covering the current prices of building materials, the questions relating to zoning, and dealing with the preparation of building codes have been issued.

In connection with simplification and the elimination of useless sizes, the important work resulting in the standardization of paving brick may be mentioned.

FIFTEENTH ANNUAL CONFERENCE ON THE WEIGHTS AND MEASURES OF THE UNITED STATES.[2]

THE Annual Conference on Weights and Measures is an unofficial body composed of state and local officials, concerned with the enforcement of weights and measures laws and ordinances, which meets once in each year to consider and solve problems arising in connection with their work. This publication is a report of the fifteenth meeting of this conference, which was attended by about 185 persons from 28 states, including officials, railroad scale men, manufacturers' representatives and others in-

[2] Miscellaneous Publication, No. 51.

terested. Addresses were given by the Secretary of Commerce, Hon. Herbert Hoover, and by the Chairman of the Committee on Coinage, Weights and Measures, Hon. A. H. Vestal, of Indiana. Perhaps the most important single subject discussed was tolerances on heavy-duty automatic scales. Very many of these scales have been put in use in the past few years and the subject of tolerances is one of very great importance. A report on the accuracy of these scales in service based on a comprehensive field investigation made by the Bureau of Standards and the Committee on Specifications and Tolerances of the Conference, was presented, as was a progress report of the Committee outlining the factors on which the tolerances should be based and suggesting tentative figures. This report was accepted and will form the basis of a further study of the subject by interested parties throughout the country. Tolerances were tentatively adopted on linear-measuring devices while tolerances on bread loaves were discussed and a committee appointed to meet with a like committee of the baking industry to consider the whole subject of uniform laws and tolerances. Other subjects of interest were methods of test of gasoline pumps, linear-measuring and leather-measuring devices, wholesale deliveries of gasoline, sale of dry commodities by weight, Federal and State approval of type of apparatus, relationship between manufacturers, merchants, and officials, a uniform ton for coal, uniform requirements for milk bottles, protection of highways by portable weighing devices, etc.

THE STRUCTURE OF MARTENSITIC CARBON STEELS AND THE CHANGES IN MICROSTRUCTURE WHICH OCCUR UPON TEMPERING.[3]

By H. S. Rawdon and S. Epstein.

[ABSTRACT.]

IN spite of the information afforded by recent investigations concerning the nature of the transformation changes in iron and steel, there still remains much to be learned concerning the visible structural features of martensite and the changes which occur upon tempering. A study of the microstructure of hardened and tempered carbon steels was carried out on a series of six steels varying from 0.07 to 1.12 per cent. carbon. These were hardened

[3] *Scientific Papers*, No. 452.

by water-quenching from different temperatures ranging from 750 to 1250° C. The effect of heating previous to quenching was also considered. The results produced by tempering were studied in hardened specimens reheated to temperatures varying from 100 to 650° C., consideration being given to the length of time the specimen was reheated. The investigation consisted largely in microscopic examination, supplemented by a study of the scleroscope hardness of the quenched and of the tempered steels.

The coarseness of the martensitic structure appears to be determined almost entirely by the temperature from which the material is quenched; the influence of the period during which the material is heated previous to quenching, at least up to four hours, is relatively very slight as compared with that of temperature.

Each crystal of austenite of the hot steel is transformed during the quenching into a system of martensitic plates or needles, the orientation of the system from any austenite being quite distinct from that produced from the neighboring ones. Martensite is formed from austenite in a manner analogous to the freezing of a solid-solution alloy, in that each of the chemically homogeneous austenite crystals gives rise to a structure that is non-homogeneous in composition. A redistribution of carbon takes place and the conspicuous martensite plates or needles are found to be distinctly lower in carbon than the "filling material." Evidence of this may be obtained from the characteristic behavior of the specimen after complete tempering, toward etching reagents. The enrichment in carbon of the filling material between the needles may be great enough so as to allow small patches of austenite to persist in the steel after quenching. Both the 0.85 C. and 1.12 C. steels showed austenite, particularly in specimens quenched from the highest temperatures. None of the other steels showed any features, however, which suggested the retention of austenite after quenching.

The changes which occur during tempering are considered under two headings: Those below and those above 250° C. The structural changes below this temperature are relatively slight and manifest themselves by the difference in the rate of etching of martensite, particularly in the steels of high-carbon content, with respect to alkaline oxidizing reagents.

By means of liquid-air treatment, it was shown that low-temperature tempering has only slight effect upon the austenite retained in high-carbon steels after quenching. Between 200 and 250° C., however, it is transformed entirely and disappears as a constituent of the microstructure in steels tempered to 250° or above.

A relatively pronounced change in structure of hardened steels occurs at approximately 250°. The martensite and austenite, if present, are transformed and the steel begins to assume a granular appearance. The rate of etching in acid reagents increases very rapidly soon after this tempering temperature has been reached. Further tempering increases the granular structure so that after heating at approximately 500° C. the individual particles of cementite may be detected under the microscope. Fully tempered steels, after being etched with a reagent which colors the cementite particles, show the unhomogeneity in composition, which resulted from the redistribution of carbon which occurred during martensite formation.

The curves summarizing the scleroscope hardness of steels tempered at various temperatures show a distinct change of slope at approximately to 250° C. Below this temperature the hardness decreases very slightly as compared with the rate of decrease above 250° C. In the steel of highest carbon content used the hardness number after a long tempering period below 250° C. was distinctly higher than after a short tempering at the same temperature. The hardening resulting from the gradual change in the austenite neutralizes to some extent the softening in the martensite which occurs readily upon tempering even at low temperatures. None of the tempered specimens, however, showed a hardness number greater than that of the initial hardness directly after quenching, as has been reported by some investigators.

An increase in the temperature from which the steels were quenched, provided this was above the Ac_3 transformation, or a long heating period previous to quenching produces no marked effect upon the scleroscope hardness of the quenched steel.

The evidence afforded by the investigation did not appear to warrant any speculative discussion concerning the ultimate nature of martensite, although several important features were revealed, which must be accounted for in any explanation of the real nature of this constituent.

THE ACTION OF CHARRED PAPER ON THE PHOTOGRAPHIC PLATE AND A METHOD OF DECIPHERING CHARRED RECORDS.[1]

By Raymond Davis.

[ABSTRACT.]

THE Bureau of Standards was recently called upon to find a method for deciphering the written and printed matter contained on charred paper.

The charred papers submitted apparently had been subjected to heat in a closed vessel, such as a safe—the paper having been converted into black sheets of carbon and not to ashes as would have been the case had they been burned in an open container.

With casual observation no traces of writing are visible, but under certain critical conditions of lighting very faint traces of markings can be seen. These traces are not sufficiently clear to permit deciphering.

In some preliminary trials made on paper charred for the purpose, conversion of the iron salts contained in the ink into colored salts was tried. These were unsuccessful.

It is known that the photographic plate, besides being sensitive to light, is also sensitive to certain gases and vapors. Some of these have the property of fogging or rendering developable such portions of the plate as are exposed to their actions. Certain other gases or vapors have the contrary property, that is, they partially or completely desensitize the plate.

For the first trial a sheet of the carbonized paper was placed between two " fast " photographic plates and kept in the dark for two weeks. On development in the usual manner a very perfect copy of both the writing and the printing was obtained. It appears that the carbonized paper contains gases that fog the photographic plate. Where the ink is present, little or no effect takes place. Apparently the ink acts as a screen, hindering the escape of the gas.

It is interesting to note that the writing on both sides of the charred paper appears, that from the back being fainter than that from the face. Apparently the ink penetrates the paper sufficiently so that its residue reduces the amount of gas escaping from beneath.

[1] *Scientific Papers*, No. 454.

No attempt was made to determine the nature of the active material contained in the charred paper. It is quite likely that it contains products similar to those obtained by the destructive distillation of wood.

Further tests showed that photographic plates of sensitiveness usually termed fast or medium are best adapted for this purpose. However, the sensitiveness to light is no definite indication of the sensitiveness to the charred paper. For example, Seed 30 and Seed 26X are of equal sensitiveness to the charred paper, the former is considerably faster to light than the latter. Very slow plates, such as " Process " are not suitable as exposure of thirty-two days shows only faint action. Photographic printing and enlarging papers are very insensitive to the charred paper.

Results obtained by the use of photographic films were very surprising, as shown by the two types of emulsions selected for the test, namely, Eastman " Portrait Film " and Eastman " Super Speed Portrait Film."

The Portrait Film showed no effect in thirty-two days. The Super Speed Portrait showed very slight but interesting effect with a sixteen-day exposure and only a little better at thirty-two days. This was just the reverse of that with the plates, the inked areas showing black on the films, whereas on the plates they show clear. That is, with the films the ink is the active portion, the charred paper produces no fogging. It was also noted that the chemical fog of development is much lighter over the portions of the film covered by the charred paper as compared with the uncovered areas.

The results suggest that there are perhaps two different kinds of gas given off, one kind by the charred paper and another by the ink, both of which fog the photographic emulsion, but the one from the charred paper more rapidly.

It was found that after a short washing these films in distilled water, for about five minutes, followed by thorough drying, gave results similar to those obtained with plates. Very good copies were obtained from washed film after eight days' contact with the charred paper.

Separate sheets of the charred paper which had been exposed to the air for several months required two weeks' contact with the photographic plate to produce a good printing negative, whereas sheets taken from a charred ledger required only one week to give

an equally good negative. It is natural to assume that the active material is gradually lost by exposure to air—the activity having dropped one-half in about two months' time. Following this, however, the rate of depletion has dropped considerably, no further reduction in activity having been observed.

TABLES FOR THE CALCULATION OF THE INDUCTANCE OF CIRCULAR COILS OF RECTANGULAR CROSS-SECTION.[1]

By Frederick W. Grover.

[ABSTRACT.]

MULTIPLE-LAYER coils are much used where a larger inductance is required than can conveniently be obtained from a single-layer coil. To reduce the considerable capacity which is associated with a simple circular coil wound in layers in a channel of rectangular cross-section, recourse is had to "banked" windings, or the layers may be spaced apart by small thicknesses of insulating material, or a "honeycomb" type of winding may be employed.

In all these cases, the inductance may be calculated with a good degree of accuracy by the formulas which apply to a circular coil with the current uniformity distributed over a rectangular cross-section. For this purpose the dimensions of that ideal coil of this type which is equivalent to the actual coil must be used. For the dimensions of cross-section there should be taken the product of the winding pitch in the layer by the number of turns in the layer for one dimension, and for the other the product of the distance between corresponding turns in successive layers by the number of layers. The mean radius of the equivalent coil is the same as the mean radius of the actual coil. Thus, the rectangular cross-section of the equivalent coil may be imagined to be made up of a rectangular array of equal smaller rectangles, with a turn of the wire of the coil at the centre of each. The inductance of the actual coil differs, of course, from that of the equivalent coil by a small amount, for which a correction may be calculated as shown by Rosa.

A number of formulas have been developed in the past for calculating the inductance of a circular coil of rectangular cross-section. Of these especial mention may be made of the formulas of Lyle, Dwight, and Butterworth, which between them cover

[1] *Scientific Papers*, No. 455.

all possible coils of this type. These formulas are, however, somewhat complicated, and calculations by them are tedious and time consuming. Furthermore, the computer is likely to experience some uncertainty in certain cases in the choice of the most suitable formula for his problem. If many calculations have to be made, some means of reducing the labor of computation and for doing away with the necessity of choosing among the formulas is a practical necessity.

Several solutions of this problem have appeared in recent years. Of these there may be mentioned the single empirical formula of Brooks and Turner, which gives an accuracy of from 1 to 3 per cent. in different cases, and the curves of Coursey and Dwight. The values calculated by Coursey for *thick* coils give only a rough accuracy on account of the formula used being unsuited for this case. Neither of these sets of curves as reproduced by the printer allow of an accuracy of better than 1 per cent. in the value of the inductance.

The tables presented in this paper are calculated from the accurate formulas cited above, more than one formula having been used wherever this was possible as a check on the results. The tabulated values are correct to a part in ten thousand, and even where a double interpolation has to be made, the error is less than one part in a thousand. If desired, curves can of course be constructed from the data of the tables, with, however, a sacrifice in accuracy.

The inductance may be calculated by either or both of the following formulas:

$$L = 0.002\ \pi^2 n^2 a \frac{2a}{b} K' \text{ microhenries} \qquad (1)$$

or

$$L = 0.001\ n^2 a\ P' \text{ microhenries}, \qquad (2)$$

in which

a = the mean radius of the equivalent coil,
b = the axial length of the equivalent coil,
c = the radial thickness of the equivalent coil,
n = the number of turns,

and K' and P' are quantities which are given in the tables as functions of the two parameters $c/2a$ = thickness divided by mean diameter and $\frac{c}{b}$ or $\frac{b}{c}$, the shape ratio of the cross-section.

Formula 1 is especially suited to long, thin coils, while 2 is better adapted to pancake coils or coils of nearly square cross-section. Either may be used, however, in any case, and thus a check on the numerical work is afforded.

Where interpolation has to be made in the tables, a greater accuracy is obtained if in 1 we write $K' = K - k$, and obtain from the tables the values of K and k separately. K is Nagaoka's constant, the value of K', which applies to a cylindrical current sheet or coil with $c = 0$. Similarly, in the case of 2 it is more accurate to put $P' = Pf$ and to interpolate for P and f separately. P is the value of P' which applies to a disk coil of zero axial thickness, $b = 0$, and is tabulated here from Spielrein's formula as a function of $\frac{c}{2a}$.

Examples are given to illustrate the use of the tables and formulas in practical cases, and the application of the tables to the calculation of the mutual inductance of coils of rectangular cross-section is treated and illustrated and the necessary formulas developed.

The formulas on which the tables are based are collected for reference in an appendix.

SPECTROPHOTOELECTRICAL SENSITIVITY OF SOME HALIDE SALTS OF THALLIUM, LEAD, AND SILVER.[6]

By W. W. Coblentz and J. F. Eckford.

[ABSTRACT.]

THIS paper, considered in connection with previous publications (*Sci. Papers*, No. 446 and one, on press), completes a study of the effect of crystal structure, chemical constitution, and atomic weight upon spectrophotoelectrical sensitivity. It is shown that these factors have a definite effect upon the photoelectrical reaction just as previously they were found to have a specific effect upon absorption and reflection spectra.

It was found that the spectrophotoelectrical reaction of the halide salts of thallium, lead, and silver is confined to a very narrow region of the violet end of the spectrum, being the narrowest and most sharply defined reaction spectra of all substances yet published, including the photoelectric gas-ionic reaction spectra of the alkali metals.

[6] *Scientific Papers*, No. 456.

Data are given showing that increasing the atomic weight of the acid element in the salts of thallium shifts the maximum of the spectrophotoelectrical reaction towards the long wave-lengths. The maximum of the spectrophotoelectrical sensitivity of Tl Cl is at 0.365μ; of Tl Br at 0.413μ; and of Tl I, at 0.455μ.

The photoelectrical sensitivity curves of the halide salts of thallium have the outline of what appears to be the typical spectrophotoelectrical reaction curve, *viz.*, a high photoeiectrical reaction on the short wave-length side of the maximum, and a very abrupt termination of the reaction on the long wave-length side of the maximum.

Lowering the temperature of Tl I to –60 C. had no appreciable effect upon the position of the maximum of the spectrophotoelectrical reaction.

Of the halide salts of lead, Pb Cl_2, Pb Br_2, and Pb I_2, only the iodide was found to react photoelectrically. The spectrophotoelectrical sensitivity curve of lead iodide appears to be complex with an ill-defined maximum in the region of 0.45μ, and sharply defined maximum at 0.52μ.

The halide salts of silver appear to be sensitive photoelectrically when melted into a vitreous or semi-vitreous mass. Silver chloride exhibited photoelectrical sensitivity in the region of 0.38μ. Silver bromide has a maximum at 0.46μ. The sensitivity curve of silver iodide appears to be wide and complex with maxima at about 0.47μ and 0.50μ respectively.

In connection with these silver halide salts, an examination of samples of silver nitrate and potassium nitrate showed no photoelectrical sensitivity.

GASES IN METALS: 1. THE DETERMINATION OF COMBINED NITROGEN IN IRON AND STEEL AND THE CHANGE IN FORM OF NITROGEN BY HEAT TREATMENT.[1]

By Louis Jordan and F. E. Swindells.

[ABSTRACT.]

THE only form of nitrogen determined in iron or steel by the Allen or acid-solution method is that present as combined nitrogen, probably existing as nitrides of iron, or of such minor constituents as manganese, or aluminum. The solution of the metal sample for nitrogen analysis is made in hydrochloric acid of sp. gr. 1.11.

[1] *Scientific Papers*, No. 457.

This solution may be carried out in a covered beaker heated on a steam bath. If solution is hastened by heating over a free flame, or on a hot plate or sand bath, ammonia is lost and low values for nitrogen result. The distillation of this solution for ammonia is best made with condensers having block tin inner tubes. Such condensers give blanks equivalent to 0.000015 g-nitrogen with the same reagents which give blanks of 0.0001 to 0.0002 g-nitrogen with glass condensers. The ammoniacal distillate is collected in 0.01 normal sulphuric acid and the excess acid titrated with 0.01 normal sodium hydroxide, using sodium alizarine sulphonate as an indicator. Estimation of the ammonia in the distillate by means of Nessler's solution gives results too low with steels containing more than 0.1 or 0.2 per cent. carbon.

It has been found that heat treatment of certain steels increased the amount of nitrogen as determined by the Allen method. Such increases have been found in an electric furnace silico-manganese spring steel, in a plain carbon steel from the outside surface of an autoclave plate, and in a series of electrolytic iron ingots. This increase did not take place in an open hearth silico-manganese steel of the same composition as the electric steel, in the plain carbon steel from the inner surface of the same autoclave plate, nor in a second series of electrolytic iron ingots. It is probable that this increase in combined nitrogen is the result of the conversion of uncombined nitrogen to nitride nitrogen by heat treatment, and that nitrogen in two forms was present originally in those samples in which the increase took place.

APPARATUS FOR THE DETERMINATION OF THE MAGNETIC PROPERTIES OF SHORT BARS.[1]

By M. F. Fischer.

[ABSTRACT.]

IN many cases it is desirable to determine the magnetic properties of materials which are available only in small quantities, such as pure alloys, alloys of experimental composition, and the like. For the correlation of the magnetic properties with various factors such as composition and heat treatment, it would be a distinct advantage if only small samples were required. The ordinary methods of magnetic testing, however, require relatively large

[1] *Scientific Papers*, No. 458.

samples, so that a method for the testing of small samples with satisfactory accuracy and speed would greatly facilitate such work. In order to meet this need an apparatus has been developed which is capable of testing such samples with a degree of accuracy sufficient for most purposes.

The method involves the comparison of the unknown sample with one whose properties have been previously determined. Because of the principle involved the apparatus is referred to as a comparator and was constructed especially to measure samples 6 mm. in diameter and of a minimum length of 10 cm.

The apparatus consists primarily of an electromagnet with yoke and pole pieces of Norway iron and with a magnetizing solenoid surrounding the yoke. Symmetrically located in the ends of the poles are two 6-mm. holes with centres 12 mm. apart in which the known bar and the bar to be tested are lightly clamped by means of thumb screws. Coaxial with these holes and held in position between the poles are two test coils of 100 turns each wound on brass forms surrounding the two bars. Each of these test coils can be separately connected to a ballistic galvanometer through the secondary of a calibrating mutual inductance.

Values of induction are measured by means of a ballistic galvanometer connected to the test coil surrounding the test bar. Values of magnetizing force are obtained by noting the inductions in the second bar, called the reference bar, and from a suitable calibration curve determining the magnetizing forces corresponding to the observed inductions.

If the two specimens were subjected to the same value of magnetizing current, the inductions in the two bars would be proportional to their respective permeabilities, and the induction in the reference bar under such circumstances could be used to directly indicate the magnetizing force. Such a simple procedure is not possible, however, as the reluctance of the joints and leakage from the bars cause discrepancies which are too large to neglect. This source of error has been overcome to a large extent, by calibrating the apparatus with standard bars of various properties which have been previously determined by a standard method.

By the use of a suitable series of calibration curves whose coördinates are the inductions in the reference bar and the corresponding values of magnetizing force as obtained from the standard bars the apparatus is capable of yielding satisfactory results.

If an unknown bar is substituted for the standard and corresponding values of induction for the unknown and reference bars are determined, these calibration curves can be used for determining the values of magnetizing force.

Values of residual induction are obtained by noting the change in induction when the magnetizing force is reduced to zero from some specified maximum.

The determination of coercive force requires the calibration of a second reference bar. This is also done by means of several standard bars whose coercive forces have been obtained by the standard method. With the reference bar and one of the standard bars in the comparator, the induction is set at the value from which coercive force is to be obtained, usually the induction corresponding to a magnetizing force of 150 gilberts per cm. The application of the coercive force of the standard bar will reduce the induction in that bar to zero and will at the same time reduce the induction in the reference bar to some other value. This value of induction and the corresponding demagnetizing force are the coördinates of a point on the calibration curve. Other points are obtained with standard bars of different coercive forces. This curve is used in subsequent testing to indicate value of coercive force and is used in a manner similar to that by which it was obtained.

This apparatus is not sensitive to external influences and is capable of producing results which, in general, are in error by less than 5 per cent. of the magnetizing force corresponding to a given induction. For certain types of material, errors greater than this may occur for low values of induction, but in any case the accuracy is determined by the degree to which the properties of the standard bar used in the determination of the calibration curve approximate those of the bar under test.

SPHERICAL ABERRATION IN THIN LENSES.[1]

By T. Townsend Smith.

[ABSTRACT.]

THIS paper presents an elementary theory of the spherical aberration of thin lenses, to give means for determining quickly the aberration of any thin lens for any position of the object,

[1] *Scientific Papers*, No. 461.

and to formulate a statement of the conditions under which the spherical aberrations of two thin lenses will compensate one another. This last is confined to the simplest case, in which the lenses are close together. The treatment is in part analytical, in part graphical.

In addition, there is included in this paper a graphical solution of the problem as to the conditions under which a two-piece lens may be achromatic, free from axial spherical aberration, cemented, and free from coma, and the shapes of the lenses necessary to satisfy these different conditions are shown. The effect of a slight change in the shape of the lenses is also indicated.

It is not expected that any of the material is really new, but the author knows of no place where the information given may be readily obtained, even piecemeal.

THE PREPARATION AND PROPERTIES OF PURE IRON ALLOYS: II. MAGNETIC PROPERTIES OF IRON-CARBON ALLOYS AS AFFECTED BY HEAT TREATMENT AND CARBON CONTENT.[10]

By W. L. Cheney.

[ABSTRACT.]

THIS paper discusses effects of heat treatment and chemical composition on the magnetic properties of a series of unusually pure iron-carbon alloys ranging from pure iron to 1.6 per cent. carbon. The alloys were prepared from deposited pure iron (obtained electrolytically) together with a regulated amount of carbon melted in a vacuum furnace.

The test specimens in the form of rods were given the following heat treatments: (1) Two sets of specimens (*i.e.*, two rods from each percentage of carbon) were hardened by quenching in oil and water from suitable temperatures. After the quenching, the specimens were accurately ground to a uniform diameter of 6 mm. and were drawn back to successively higher temperatures (alternating for the two sets) by heating in a suitable bath and allowing to cool slowly in lime.

Another set of specimens was annealed by slowly heating to a desired temperature in an evacuated electric furnace and allowing them to cool very slowly.

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[10] *Scientific Papers*, No. 463.

After each heat treatment, measurements were made of the normal induction for magnetizing forces up to 2500 cgs. units, and of the residual induction and coercive force from maximum magnetizing forces of 100, 200 and 1000 cgs. units. Other magnetic quantities could be calculated from the observed values.

Micrographs, all at a magnification of 500 diameters, represent the average structural condition shown by etching in a 5 per cent. alcoholic picric acid. Such micrographs were made of the quenched specimens, those drawn back to 270° C., those drawn to 700° C., and the annealed specimens.

The results of the investigation may be summarized as follows:

1. The hardened alloys when drawn back to successively higher temperatures show certain magnetic transformations: (*a*) A rapid rise in the induction (*H* constant) between 200° and 250° C., finally reaching a maximum at some definite temperature and gradually decreasing. (*b*) A similar trend of the residual induction but less rapid rise, with a delayed maximum and a somewhat more rapid descent following. (*c*) Marked changes in the coercive force; the greatest decrease being between 200° C. and 300° C. A cusp in the curve occurs in the neighborhood of 470° C., indicating a structural change of the material at this temperature. (*d*) Similar changes are shown by considering the product $B_m \times H_c$, which is proportional to the dissipation of energy owing to hysteresis. (*e*) The reluctivity relationship is employed to compute the saturation intensity of magnetization. In some cases this maximum value of the intensity was single valued, in some cases double valued, and in only a few cases triple valued. Micrographs confirmed in the majority of cases the fact that the number of values of I_m represents the number of constituents present in the material. (*f*) The intercept value of the reluctivity line also serves to detect transformations and to indicate the presence of more than one constituent. (*g*) Values of the maximum permeability show very great differences for certain alloys as compared with small differences in other magnetic quantities.

2. For the annealed alloys: (*a*) Magnetization curves (for low inductions) show a decided change in the steepness of the curve in the second stage and hence a change in the permeability, with a change in the percentage of carbon content. (*b*) The

coercive force has a maximum for the highest carbon used. (*c*) The maximum intensity of magnetization which was double valued except for pure iron where it was single valued, and for 1.55 per cent. carbon where it was triple valued, decreased with an increase in the carbon content. (*d*) Micrographs confirmed the number of constituents which might be predicted from the number of values of I_m in all cases except the 1.55 per cent. carbon.

3. The experiments bring out the following points: (*a*) The sensitiveness of magnetic quantities to any slight changes of metallographic structure as a result of heat treatment. (*b*) The necessity of very accurate control in heat treating specimens for a study of their magnetic properties. (*c*) No definite quantitative relationship can be established between the various magnetic quantities and the heat treatment, or between the various magnetic quantities and the chemical composition. (*d*) All magnetic quantities must be considered in studying the effect of heat treatment and chemical composition.

VARIOUS PHOTOELECTRICAL INVESTIGATIONS.[11]

By W. W. Coblentz.

[ABSTRACT.]

THE purpose of this paper is to give miscellaneous data which were obtained in connection with the general investigation of photoelectrical sensitivity, but not heretofore published.

Data are given on the preparation and testing of various sulphides of molybdenum, MoS_2, MoS_3, etc., the object in view being the artificial production of molybdenite MoS_2, which is photoelectrically sensitive.

The results thus far obtained show that all the wet and dry process preparations of MoS_2 are photoelectrically sensitive, but the intrinsic sensitivity is far less than that of the photosensitive spots found in some samples of the natural mineral.

From the data at hand it appears that this photoelectrical sensitivity is inherent in the MoS_2.

Spectroscopic and qualitative chemical analysis shows no marked difference in the constituents of samples of molybde-

[11] *Scientific Papers*, No. 462.

nite, excepting a larger iron content in the material having a high photoelectrical sensitivity.

A number of samples of molybdenite were subjected to heat treatment (1) by passing electrical current through them and (2) by heating them, in some cases under high pressure, in an oven.

The conclusion to be drawn from these tests is that slow heat treatment has no marked permanent effect upon the intrinsic photoelectrical sensitivity in the temperature range up to 500° C. At a temperature of about 600° C. the sensitivity appears to be permanently decreased. Raising the temperature to a low red (about 700° C.) heat destroyed the photosensitivity.

In the heat treatment of stibnite it was found that, aside from a possible shift of the maximum towards the long wavelengths, the spectrophotoelectrical sensitivity curve of the melted and slowly recrystallized material is practically the same as that of the average curve of the native mineral.

Samples of molybdenite and stibnite were subjected to electrical treatment which consisted in passing an alternating current through them for certain intervals of time and then noting the effect upon the photoelectrical sensitivity. The conclusion to be drawn from these experiments is that an alternating current has no marked permanent effect upon the photoelectrical sensitivity of molybdenite and stibnite.

Among the miscellaneous artificial preparations examined for photoelectrical sensitivity were: molybdenum oxide; various sulphides of tin, tungsten, and uranium; also Bi_2 Te_3 and Mo Se_3. None of these preparations showed a marked photoelectrical sensitivity.

Data are given on the negative spectrophotoelectrical reaction in molybdenite, confirming and extending previous observations.

A sample of molybdenite was found which has a uniform sensitivity over a wide range of the visible spectrum, and a photoelectrical reaction which is proportional to the intensity of the radiation stimulus. This lends encouragement to the efforts which should be made to produce for radiometers a photoelectrical material, which will have these properties.

From a special examination of these two minerals it appears that molybdenite and stibnite have no sharp bands of photo-

electrical sensitivity in the extreme ultra-violet, but that the reaction gradually decreases with decrease in wave-length.

Several spectral response curves are given of Case's barium and strontium photoelectric cells, which have maxima at 0.42μ and 0.39μ respectively. By covering the barium cell with a suitable screen, a spectral response curve is obtained which coincides closely with the visual response of the average eye.

Data are given on the spectrophotoelectrical reaction of cuprous oxide; also of a lead antimony sulphide Pb_3 Sb S_3, which shows that the spectrophotoelectrical reaction spectrum of a compound is not the composite of the reactions of the constituents which may be photoelectrically sensitive.

Iodine was found to be photoelectrically sensitive with a maximum in the region of 0.53μ to 0.55μ.

PREPARATION AND PROPERTIES OF PURE IRON ALLOYS: III. THE EFFECT OF MANGANESE ON THE STRUCTURE OF ALLOYS OF THE IRON-CARBON SYSTEM.[12]

By Henry S. Rawdon and Frederick Sillers, Jr.

[ABSTRACT.]

MANGANESE is one of the essential materials in the manufacture of steel. In addition to its function as a deoxidizing and a "desulphurizing" agent for steel, it is also valuable for conferring certain desired mechanical properties upon the material, such as high tensile strength. A recent investigation of the Bureau of Standards is concerned with this latter phase of the functions of manganese in steel.

By means of an extensive series of alloys of iron-carbon and manganese with carbon varying from 0 to 1.6 and manganese, 0 to 2 per cent., prepared from pure materials, the effect of manganese on the structures, and hence on the properties, was determined.

The effect of manganese, as observed in annealed alloys, is to confer upon the pearlite a very fine grained or sorbitic structure, even after slow cooling. The relative amount of pearlite present is considerably greater in the alloys of high manganese content than in corresponding ones low in this element. A pronounced increase in Brinell hardness of the annealed alloys accom-

[12] *Scientific Papers*, No. 464.

panies the change in structure produced by the addition of manganese. The addition of manganese causes a shift in the eutectoid ratio toward lower carbon content. One per cent. of manganese lowers it to approximately 0.78 per cent. carbon.

In the normalized alloys a pronounced decrease in grain-size was found in those of higher manganese contents, in addition to the structural effects mentioned above. In the annealed specimens no noticeable differences in grain-size were detected for high and low manganese content in alloys of any given carbon content.

The well-known effect of manganese in lowering the transformation temperatures of the materials will account in part for the observed structural changes. It appears also that manganese renders steel more "sluggish" and less responsive to structural changes than many of the other elements which produce a similar lowering of the critical temperatures. While the results of the structural examination will not warrant any definite conclusions concerning the use of manganese as a strengthening element in steel, the results obtained strongly support previous recommendations which have been made by different metallurgists concerning the advantages to be gained from the use of higher manganese, particularly in low and medium carbon steels.

RECLAMATION OF USED PETROLEUM LUBRICATING OILS.[13]

By Winslow H. Herschel and A. H. Anderson.

[ABSTRACT.]

As a measure of conservation of an irreplacable natural resource it is desirable that oils which are dirty or otherwise unfit for further use should be purified or reclaimed. Automobile oils are subjected to severe conditions of service, and may be taken as an example to illustrate the deterioration of oils in use. Aided perhaps by the catalytic action of metal parts and metal particles worn from the bearings, the heat causes the oils to oxidize in use, with the formation of oxidation products of an asphaltic or tarry nature and an increase in organic acidity. The heavy ends of the fuel, similar in nature to kerosene, leak past the piston rings and work their way down into the oil in the crank case, causing what is known as crank case dilution.

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[13] *Technologic Papers*, No. 223.

To bring the oil back to its original condition, it is evidently necessary to distil off the heavy ends of the fuel, conveniently by heating with steam. As the heating continues and the kerosene is driven off, samples are taken from time to time and tested for flash point. The increasing values obtained in this test indicate the progress being made. It is also necessary to remove the sediment, consisting of oxidation products, road dust, and metallic particles, and this may be accomplished by filtering or by precipitation, using sal soda as a coagulant.

In tests with an apparatus for reclaiming oil by use of a coagulant it was found that the reclaimed oils would pass the usually accepted tests such as viscosity, flash point, and sediment, although the flash point will be slightly lowered. The tests were not conclusive as regards the efficiency of the process in reducing organic acidity since the oils had not been long enough in use to become very acid. The necessity of reducing the acidity to a very low value is open to question, since there appears to be no danger that the acidity would ever become high enough to cause corrosion, except perhaps of lead or zinc. There is evidence, at least as far as Eastern oils are concerned, that the higher the acidity the less the demulsibility or resistance of an oil to emulsification, but investigation of California oils showed that in some cases they had a higher acidity than ever observed for Eastern oils, and yet would pass the test for demulsibility. If, therefore, there is a necessity for testing for organic acids, it must be on the ground that oils high in acidity will not prove durable in use; but this has not been conclusively proved. The difficulty is increased by the possibility that different oils contain different acids, some of which may be more undesirable than others, but which can not be distinguished by simple chemical tests. In fact, the difference in demulsibility of Eastern and California oils of the same organic acidity would indicate that there was a difference in the kind of acid present.

A possible advantage of oils of high acidity is a low coefficient of friction when used in a bearing. It has been found that if a minute quantity of acid from fatty oils is added to mineral oils, the friction, when the oil is used as a lubricant, is considerably reduced, and it is possible that petroleum acids will have the same effect. In many cases it has been found that an oil which showed a low coefficient of friction would also show a low interfacial ten-

sion. On this account an interfacial tension apparatus was used to determine the effect of organic acids upon the friction, but the results were inconclusive, and tests with an oil friction testing machine are planned. If it should prove that high organic acidity is necessary in order that the coefficient of friction may be low, then it may be necessary to compromise between too high a coefficient of friction or too high an acidity, since the latter would indicate the presence of unsaturated compounds and a tendency toward the rapid formation of oxidation products and possibly sludge.

The cause of sludge formation is not clear, but it appears to differ from an emulsion in requiring considerable time for its development. As an oil continues for a long time in use, it accumulates road dust, carbon and other materials in a finely divided state, and the most probable explanation appears to be that sludge is a case of a permanent emulsion due to carbon or dust in a colloidal condition. However this may be, it is evident that all finely divided as well as coarse impurities should be removed from used oils in reclaiming.

What improvements it may be necessary to make in reclaiming processes will depend upon the progress made in selecting or devising a test for durability of an oil in service. The tests at present available for consideration are organic acidity, sulphur content, carbon residue, demulsibility, and Waters carbonization. When it is decided which of these tests are vital, the reclaiming process may be modified, if necessary, so that the reclaimed oils will meet these tests.

A NEW METHOD FOR DETERMINING THE RATE OF SULPHATION OF STORAGE BATTERY PLATES.[11]

By G. W. Vinal and L. M. Ritchie.

[ABSTRACT.]

THIS paper describes experiments which have been made to develop a speedy and accurate method for measuring the effect of impurities in storage battery electrolyte. In the present paper the fundamental theory of the method and measurements of the rate of sulphation of the plates in the pure acid are given. An extension of the investigation is planned which will include the effect of added impurities following the method here described.

[11] *Technologic Papers*, No. 225.

Preliminary experiments in which small cells were "poisoned" by the addition of the various substances to be studied showed that accurate and consistent results were difficult to obtain. Because of the inaccuracies of this method and the time required it was decided to determine the effect of impurities in terms of the rate of the reaction taking place at the plates. This may be accurately determined in a short time by successive weighings of the plates immersed in solutions which are maintained at constant temperature. The plates were suspended in the electrolytes from the arm of a sensitive balance. By this arrangement, it was possible to weigh each plate without exposing it to the air. The jars containing the electrolyte were contained in a thermostat bath of water which could be controlled to within 0.01° C. at any desired point within the range 20 to 40° C. Weighings of the plates were made daily and the results computed as the increase in weight per hour.

The reaction at the negative plate may be both chemical and electrochemical. The measurements show that the former predominated. The rate of sulphation of these plates was determined in solutions saturated and unsaturated with lead sulphate. The rate of sulphation is greater in the latter case. Significant differences were observed between the results obtained in measuring plates made by different manufacturers.

The rate of sulphation of the negative plates increased as the concentration of the electrolyte and the temperature were increased. The rate of sulphation of the positive plates is much less than for the negative plates. It is assumed to be electrochemical in origin. Corrections for the buoyancy of the electrolyte are necessary. It is possible to compute from the electrochemical equivalents the number of ampere-hours of discharge occurring as local action.

The results of these measurements indicate that this is a satisfactory method for measuring the effect of impurities at the negative plates and probably at the positive plates also. It is more difficult to interpret the results obtained at the positive plates. The method is not immediately applicable to the study of such impurities as serve as oxygen carriers, but can be used to determine quantitatively the effect of metallic impurities of other kinds for which accurate data are lacking at present.

TESTING OF BAROMETERS AND ALTIMETERS.[15]

[ABSTRACT.]

BUREAU of Standards Circular No. 46 discusses methods of testing mercurial and aneroid barometers. It first considers the mercurial type. A distinction is made between the instrumental corrections made necessary by mechanical defects and corrections which must be applied to reduce the readings to standard conditions of temperature and gravity. In general, the instrumental corrections of mercurial barometers are combined and the resultant correction is expressed as a single numerical quantity. When the mercurial barometer is to be used where high accuracy is required an additional correction must be applied to allow for residual gas in the tube. This is called the gas correction. Each precision barometer has to be carefully investigated for this effect and an empirical correction curve or table prepared.

Aneroid barometers are next discussed. This type is used to a large extent: (1) For weather observations; (2) for the determination of altitude, either in mountain climbing or where rapid rates of change of pressure are involved as in aviation; (3) in establishing contour lines, and (4) for a great many engineering purposes where extreme accuracy is not required.

Unlike mercurial barometers, aneroid barometers show errors which depend upon the conditions under which the instrument is used. These are discussed below. An aneroid does not have the disadvantage that its corrected reading must be reduced to standard conditions of temperature and gravity, as is the case with mercurial barometers.

The errors of aneroid barometers are classified as transient, secular, and inherent. Transient errors are those due to the aneroid not being in a physically steady state, while secular errors are those due to changes taking place over a long period of time. Both of these classes of errors can be avoided by careful selection of the instrument. The inherent errors, *i.e.*, those due to imperfections of design or construction and to the physical properties of the material used in construction cannot be completely eliminated. Inherent errors are further subdivided under three heads, namely, mechanical, thermal, and elastic errors.

[15] Circular, No. 46.

Precautions to minimize the effects of mechanical errors are: First, always to read the aneroid in the position in which it was tested; and, second, to tap the instrument sharply just before reading.

Thermal errors are those due to the expansion of the parts and to the change of the stiffness of the elastic elements of the aneroid (the spring and vacuum chamber) under varying temperature. Aneroids which are marked "compensated" are compensated only for the effect of the changes of temperature on the reading at sea level pressures, and not for the changes of temperature at lower pressures.

The elastic errors are irreversible time effects caused by the imperfect elasticity of the metal of the aneroid vacuum chamber and springs. They may be designated as: Drift, which is the increase of reading when the instrument is held at a constant low pressure for several hours; hysteresis, which is the excess of the reading with increasing pressure over that with decreasing pressure and which is also evidenced by the fact that the reading at any given pressure depends on the previous rate of change of pressure; and after effect, which is the amount by which the pointer fails to come back to the true reading after any complete cycle of pressure change.

In this connection it is noted that during the past few years the Bureau of Standards has constructed aneroid barometers in which all the common errors of ordinary instruments have been practically eliminated. These instruments, although designed for use in aviation, nevertheless involve the same principles as those to be applied in the design of precision engineering aneroids.

The Bureau of Standards methods of testing aneroids are discussed in detail in Circular 46. These tests are conducted for the purpose of determining the magnitude of the errors, so that the proper corrections can be made in the use of the instruments.

Tables of tolerances for aviation, and for engineering and surveying aneroids are given, also the pressure-altitude table which is used in the United States in calibrating altimeters.

Instructions for applying for tests at the Bureau of Standards and the schedule of fees for the various tests are included.

BIBLIOGRAPHY OF SCIENTIFIC LITERATURE RELATING TO HELIUM.[16]

THE first edition of the Bibliography of Scientific Literature relating to helium has been revised, and references to the literature published during the years 1919–1921 have been added.

As in the first edition, the titles are grouped under numerous headings and so arranged under each heading that related articles will appear together in their chronological order. Approximately 600 references are given of which about one-third have been added since the first edition.

DESCRIPTION AND OPERATION OF AN ELECTRON TUBE DETECTOR UNIT FOR RADIO RECEPTION.[17]

[ABSTRACT.]

THE apparatus now in use for radio reception, except the most simple types, uses electron tubes. This circular is one of a series of circulars on the construction of simple receiving sets. Bureau of Standards Circulars Nos. 120 and 121 were the first two of this series. Very simple receiving sets such as those described in Circulars Nos. 120 and 121 may use a crystal detector instead of an electron tube. For a description of the electron tube and the principles of its operation reference may be made to "The Principles Underlying Radio Communication," Signal Corps Radio Communication Pamphlet No. 40.

Electron tubes are used for reception in many different kinds of circuits. One of the most elementary is as a simple detector. It is also possible to use electron tubes in reception in circuits using various kinds of amplification, or regeneration, heat reception, or other methods. For descriptions of various kinds of tube receiving circuits, reference may be made to the book, "The Principles Underlying Radio Communication," or to one of various other books now available, of which a list may be found in Bureau of Standards Circular No. 122 (price, 5 cents). A simple tube detector set will not serve to receive signals transmitted by continuous wave radio telegraphy.

This circular describes a simple electron tube detector receiving set and gives a method of operating it. This set with electron

[16] Circular, No. 81.
[17] Circular, No. 133.

tube detector is more sensitive than a set employing a crystal detector, and may be expected to give more satisfactory results.

An antenna, lightning switch, ground connection and telephone receivers, which are used in this set, have been described in Bureau of Standards Circular No. 120. Tuning devices for use with this electron tube detector set may be the tuning coil described in Circular No. 120, or the two-circuit coupler and variable air condenser described in Circular No. 121. While the two-circuit tuner will be somewhat more selective than the single-circuit tuner, as stated in Circular No. 121, its use is not absolutely essential. The more selective receiving set can be used for picking out a signal which it is desired to receive from among a number of signals of approximately the same wave-length which are being transmitted at the same time. The two-circuit tuner is somewhat more difficult to operate than the single-circuit tuner.

For an electron tube detector unit, it is necessary to have an electron tube, socket for the tube, filament rheostat, grid leak, grid condenser, by-pass condenser, binding posts, and other minor accessories. It is also necessary to have a 6-volt storage battery, and a " B " dry battery of 22½ to 45 volts. Most of these parts should be purchased, although some can be made at home if desired. The cost of the complete electron tube detector unit, including the tube and batteries, may be expected to be from $23 to $37. This estimate is exclusive of the cost of tuning device and telephone receivers described in Bureau of Standards Circulars Nos. 120 and 121, which may be from about $10 to $20. No estimate is made of the cost of equipment for charging storage batteries.

The electron tube, socket, condensers, filament rheostat, grid leak and other parts of the detector unit are mounted on a wooden base and panel. The wood for the base and panel should be thoroughly dry and should preferably be protected by a coat of good electrical insulating varnish.

A complete description of the method of assembling and wiring the detector unit is given. Illustrations are given showing the arrangement of the various parts and the complete assembled detector unit. The method of operating the set is also given.

UNITED STATES GOVERNMENT SPECIFICATION FOR FIRE EXTINGUISHING LIQUID (CARBON TETRACHLORIDE BASE).[18]

[ABSTRACT.]

FEDERAL SPECIFICATIONS BOARD STANDARD SPECIFICATION NO. 36.

THIS specification was prepared by a technical committee of the Federal Specifications Board and before final approval was submitted to the Underwriters' Laboratories and to a large number of manufacturers of such products, whose suggestions were carefully considered. The specification was promulgated as a Government Standard by the Federal Specifications Board on July 3, 1922, and gives the general requirements and detailed methods of sampling and testing. The general requirements are:

The liquid shall be capable of extinguishing fires caused by the burning of inflammable liquids and solids, shall be a non-conductor of electricity, and shall consist of carbon tetrachloride containing other suitable products necessary to produce a liquid conforming to the following requirements when tested according to the methods herein stated:

(1) *Appearance.*—It shall be a clear, homogeneous, mobile liquid.

(2) *Specific Gravity.*—The specific gravity at 15.5°/15.5° C. shall not be less than 1.500.

(3) *Cold Test.*—The liquid must have a cold test not higher than minus 45.5° C. (minus 50° F.).

(4) *Distillation.*—Not over 2 per cent. shall distil below 60° C. At least 90 per cent. shall distil between 70° and 80° C. At least 99 per cent. shall distil below 100° C.

(5) *Impurities.*—The liquid shall be free from nitrobenzene, water, acid or alkali, and free halogens, and shall not contain more than 1.0 per cent. by weight of carbon disulphide. It shall not corrode metals used in fire extinguishers.

CAUSTIC MAGNESIA CEMENT.[19]

[ABSTRACT.]

THE cement resulting from the reaction of caustic magnesia with a solution of magnesium chloride has been known for more than half a century, and some of the products made therefrom,

[18] Circular, No. 134.
[19] Circular No. 135.

in the form of resilient flooring, stucco, and ship decking, have been on the market for considerably more than half that period. However, on account of the almost universal practice of hiding the nature of the products under various proprietary trade names, the public has been kept from realizing the wide use and the general qualities of the product.

Caustic magnesia results from burning magnesite at a temperature of 800° to 1100° C. In this country the magnesite used is the amorphous variety and occurs in California or is imported from Greece or India. After calcination the material is ground and then mixed with the required aggregates to produce any of the products desired. Unlike Portland cement, the general public does not come into contact with the cement itself, but only with the mixture of cement and aggregates which are mixed with the chloride solution after delivery to the job.

References are given to the discovery and early history of this cement. A summary of the investigative work dealing with the process and products of setting is also presented. None of these has satisfactorily explained these phenomena, and conclusive research work remains to be done.

The paper gives certain typical formulas for making flooring and stucco. These are, however, only "typical" and may with the magnesia available in any case, or with the available aggregates, produce very unsatisfactory results unless materially modified. These formulas should first be tried by making test panels and noting shrinkage, expansion, or warpage, and test pieces to determine tensile or transverse strength. The deportment of these test specimens will indicate what modification of the formulas is required. The same test procedure should be followed with each new shipment of caustic magnesia or constituent aggregates. This is necessitated by the readiness with which the properties of the oxide are modified by storage and by small amounts of impurities in the aggregate, or by improper grading of the latter.

On account of the need for testing, certain test requirements and methods for conducting these are given. These are not presented in the form of specifications and methods of tests at the present time on account of the need of further study, but will serve as an outline for those desiring to know more of the caustic magnesia they are using.

SPECIFICATIONS FOR NUMBERED COTTON DUCK FOR GOVERNMENT AND COMMERCIAL USE.[20]

[ABSTRACT.]

THESE specifications were prepared by a committee of manufacturers appointed by the Cotton Duck Association and representatives of the Bureau of Standards, War Department, Navy Department, Panama Canal, and other Government departments. Each manufacturer supplied his complete range of weights and constructions of both medium and hard texture ducks for laboratory tests on the physical measurements and performances for determination of fair tolerances and requirements.

On final acceptance, it was decided that inasmuch as these specifications were fair and called for a high grade of material, especially in the care and quality of manufacture, it would be to the advantage of the consumer and manufacturer to use these specifications in obtaining a cheaper product by reason of wide acceptance and quality, taking steps to have the Government use the specifications and eventually to have the commercial user accept them. Recommendation for acceptance has been made by the Textile Technical Committee of the Federal Specifications Board.

There are embodied in these specifications two very important developments in the nature of standards of measurements. The manner of expressing the weight per unit area has been changed tentatively from the 22-inch basis to the 36-inch or square-yard basis. Both are recorded in these specifications as it is realized that the change must come gradually. This attempt to standardize on the square-yard basis will include all types of duck, among which are awning duck. A conference in regard to the latter material was held by the Cotton Duck Association and the National Association of Tent and Awning Manufacturers in an effort to substitute the square-yard basis for the 29-inch basis which the latter association was attempting to establish through state and federal legislation in order to do away with the present misunderstanding.

The second development is the establishment of a standard method of testing the breaking strength of ducks. The results of tests by the various methods used were studied, resulting in

[20] Circular, No. 136.

the selection of the 1-inch and 1 by 3-inch grab method. The Textile Technical Committee of the Federal Specifications Board has planned to recommend this method only in all specifications for duck, and the American Society for Testing Materials has been asked to consider this method as a replacement of their recommended 1-inch-strip method for tire ducks.

In these specifications, the requirements are such that no changes will be necessary in any one mill, as the minimum thread count allows a manufacturer to exceed in this regard to conform to his equipment, while the breaking strength is sufficiently high to guarantee a good quality of duck. This item was especially called for by the manufacturers' committee in their desire to raise the standard of the trade.

The material will be purchased by expressing the following: (*a*) Number of duck or weight per square yard; (*b*) texture (medium or hard); (*c*) width; (*d*) yardage; (*e*) use; (*f*) statement as to whether or not material is to conform to standard specification.

Study of the Spectrum of the Light Emitted in the Triboluminescence of Sugar. H. LONGCHAMBRON. (*Comptes Rendus*, June 19, 1922.)—When lumps of sugar are broken flashes of light appear. A few observations made on this light have seemed to indicate that the spectrum is continuous. Such is not the conclusion to which the present paper comes. The sugar was broken in air at atmospheric pressure in front of the slit of a spectrograph for a period of more than four hours. The integrated impression of the several flashes on the plate showed a series of 23 bands very narrow and well separated. These correspond to most of the bands of the second positive band spectrum of nitrogen and to no other spectrum. It is the spectrum of the electric glow in air. Air charged with sugar powder made by breaking up lumps has an electric charge, as is shown by its discharging a charged electroscope over which it is made to flow. Perhaps the flash occurring at the moment of fracture arises in this way. The two resulting fragments may have opposite electrical charges. As they are separated a glow discharge forms between them, which, of course, has the same spectrum as the glow otherwise produced. This explanation is supported by the following experiment: Lumps of sugar were placed in a glass vessel and were shaken against the walls in order to break them. When the air pressure in the vessel was from 4 to .1 cm. of mercury, the light of triboluminescence was more intense than at atmospheric pressure and occupied a much larger space around the point of rupture.

This light at lower pressures was, however, fainter than at atmospheric pressure.

After the shaking of the sugar the walls became covered with the resulting powder. When, then, the air pressure within was rapidly varied, though in all cases maintained rather low, the entire mass of enclosed air glowed brightly, especially near the bits of sugar and the parts of the walls covered with dust. G. F. S.

A New Method of Power Transmission.—Considerable literature has recently appeared concerning a new method of power transmission, invented by Constantinesco. It depends on the propagation of waves of condensation and rarefaction through liquids, water, being, of course, the most available. The liquid does not flow in the pipe. A paper by Walter Haddon gives a large amount of detail of the apparatus to be used, and a recent communication to the North-east Coast Institution of Engineers and Shipbuilders presented some of the mathematical and physical features of the subject. Five methods of power transmission have been long in use: Steam, direct mechanical power, electric, compressed air and hydraulic. The new method is, therefore, considered as a sixth one and is claimed to have very important advantages. At first it may be thought that wave transmission is merely a form of hydraulic action, but there is a wide difference. In hydraulic transmission there is a flow of liquid, but in wave transmission the liquid does not flow. The principle may be illustrated by assuming two cylinders each with a plunger and connected by pipe, the whole apparatus being completely filled with water. If one plunger is moved rapidly up and down it will set up waves of compression at each downward stroke, which will travel through the water at a speed stated to be about 4800 feet per second, and exert a pressure on the other plunger. If the distant plunger is loaded, a reciprocating motion can be established as long as power continues to be applied to the first apparatus. It is claimed that the principle has been brought to practical application, with the advantages of: Simplicity, adaptability, portability, low initial cost and low maintenance charges. A condition of satisfactory operation is that the whole apparatus shall be filled with liquid to the complete exclusion of air, which is secured by special appliances. Wave transmission can produce rotary motion by single phase (one liquid column) or by three phase (three column). The method was first applied to rock drills, riveters, and pile drivers, in which reciprocating motion is employed. By a modification the water can be allowed to flow out, and thus a dustless rock drill has been devised. It is claimed that in a properly constructed line, no appreciable rise of temperature occurs. In some cases oil may be used as the transmitting liquid. Pamphlets describing the methods, apparatus and many possible applications have been issued. H. L.

NOTES FROM THE RESEARCH LABORATORY EASTMAN KODAK COMPANY.*

NOTE ON THE ENERGY EXCHANGES IN THE FORMATION OF THE LATENT IMAGE OF A PHOTOGRAPHIC EMULSION.[1]

By S. E. Sheppard and E. P. Wightman.

THE authors present a recalculation of some energy calculations by Volmer showing the number of molecules per grain affected by the "schwellenwert" (visible threshold value) exposure and of the ratio of altered to unaltered molecules in a grain of the size assumed. Evaluation of the possible energy changes considered here are to be presented in a future paper.

ELASTICITY OF PURIFIED GELATIN JELLIES AS A FUNCTION OF HYDROGEN ION CONCENTRATION.[2]

By S. E. Sheppard, S. S. Sweet, and A. J. Benedict.

INVESTIGATION has been made of the relation of the jelly strength (modulus of rigidity) of purified gelatin jellies at different gelatin concentrations and over a wide range of hydrogen ion concentrations. The gelatin was demineralized and freed from products of hydrolysis by successive electrolysis and precipitation with acetone. The hydrogen ion concentration is expressed as the Sorensen value P_H, and it was found that the maximum jelly strength is produced between $P_H = 7$ and $P_H = 9$. No definite minimum was observed at the isoelectric point 4.7 – 4.8, but the curve has a slight shoulder in this region after which for $P_H < 4$, the jelly strength falls off very rapidly, as it does also for $P_H > 10$. It was found, further, that amounts of aluminum, equivalent to only 0.01 to 0.1 per cent. of alumina, based on dry gelatin, produced very considerable changes in the jelly strength-P_H curve. The total jelly strength was greatly increased, and a new maximum was developed at about $P_H = 4.0$. These results are discussed in connection with the theory of gelatin viscosity and elasticity. A misleading statement on Poisson's ratio (for gelatin jellies) in a previous paper, and in the literature of the subject, is corrected.

* Communicated by the Director.

[1] Communication No. 151 from the Research Laboratory of the Eastman Kodak Company and published in *J. Opt. Soc. Amer.*, Nov., 1922, p. 913.

[2] Communication No. 132 from the Research Laboratory, Eastman Kodak Company, and published in *J. Amer. Chem. Soc.*, Sept., 1922, p. 1857.

THE GRAININESS OF PHOTOGRAPHIC MATERIALS USED IN THE MOTION PICTURE INDUSTRY.[3]

By A. C. Hardy and Loyd A. Jones.

AN instrument used for measuring the graininess of silver deposits in photographic materials is described. The essential principle involved is the determination of the distance at which the graininess of the deposit under consideration, which has been magnified to a definite predetermined extent, is just invisible. It is shown by the aid of photomicrographs that the readings obtained by this instrument represent the graininess of the material as this term is understood by the photographer. The influence of various steps in the preparation of the motion picture positive upon the graininess of the resultant picture has been determined.

It was found that a negative exposure in the taking camera had marked influence on the graininess of the resulting positive print, the minimum graininess being obtained by a minimum exposure.

The time of development of the negative had very little influence on the graininess of the resulting print when a constant positive quality was maintained.

Dilution of a developing solution in general produced a slight increase in graininess.

Graininess was found to be almost entirely independent of the developing agent used for the development of a negative.

Fixing, washing, and drying conditions were found to have very little effect on graininess.

Prints made by ultra-violet light showed a measurable degree of graininess. This was also found to be the case when diffused light was used in making the prints.

An explanation is offered for the excessive graininess which sometimes occurs with certain types of subjects. This is probably due to the nature of the subject which requires the rendering of large unbroken areas by positive densities which lie near the maximum graininess. The various remedies for this condition are discussed.

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[3] Communication No. 145 from the Research Laboratory of the Eastman Kodak Company, and published in *Trans. Soc. Mot. Pict. Eng.*, No. 14, May, 1922, p. 100.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

EFFICIENCY OF THE PALMER APPARATUS FOR EXPLOSIVE CARBONACEOUS DUSTS.[1]

By L. J. Trostel.

[ABSTRACT.]

THE efficiency of the Palmer dust sampler was determined, on a weight basis, on heavy suspensions of ten dusts of varying chemical and physical properties, which are explosive hazards in the elevator, milling, and chemical industries. Microphotographs of the various dusts tested were made.

The sampler retained an average of 98.2 per cent. of the dust added to it.

There is no evidence to show that the efficiency is appreciably affected by the varying of the sampling rate from 3 to 5 cubic feet per minute under the conditions of the test.

The efficiency appears to increase with the weight of dust collected, up to certain limits.

The maximum weight possible to collect efficiently ranges from approximately 1.5 grams to 3.0 grams, depending upon the nature of the dust.

The efficiency is higher when dusts of large particle-size are being collected.

CHEMICAL CHANGES IN CALCIUM ARSENATE DURING STORAGE.[2]

By C. C. McDonnell, C. M. Smith and B. R. Coad.

[ABSTRACT.]

COMMERCIAL calcium arsenate in the dry powdered form manufactured for insecticidal purposes absorbs carbon dioxide slowly from the atmosphere during storage and increases slightly in water-soluble arsenic-oxide content, unless it is packed in containers that are practically air-tight. The rates of these changes show a close relationship and depend largely upon the type of container in which the material is packed.

* Communicated by the Chief of the Bureau.

[1] Published in *J. Am. Soc. Heat.-Vent. Eng.*, **28**, Dec., 1922, 853.

[2] Issued as *U. S. Dept. Agr. Bul. 1115*, Nov. 28, 1922.

A PHYSICAL AND CHEMICAL STUDY OF MILO AND FETERITA KERNELS.[3]

By George L. Bidwell, Leslie E. Bopst and John D. Bowling.

[ABSTRACT.]

ON the whole, kafir, corn, milo and feterita resemble one another in composition and appearance. The proximate constituents of the kernels of these sorghums indicate their value as food for man and domestic animals, and show the possibility of their being used as raw products in certain important commercial operations having for their purpose the manufacture of starch, syrup, alcohol, and oil, when proper machinery and processes have been devised. It has been found, however, that it would probably be impracticable to use them commercially for malting purposes.

SUGGESTIONS FOR THE PREVENTION OF FOOD POISONING.[4]

By Charles Thom.

[ABSTRACT.]

THE following practical summary of the precautions necessary to avoid food poisoning are based on the present status of information on food infections of the enteric group and botulism:

1. Food to be eaten raw should be fresh, clean, sound, and free from stale odors, from slimy, rotting areas, from discolorations, and from mold. It should be carefully washed in an abundance of bacteriologically clean water (that means drinking water).

2. Sound food freshly cooked does not cause food poisoning.

3. Moist or soft cooked food if held for more than a few hours should be kept in a good refrigerator. If such refrigeration is impossible, the food should be recooked before serving.

4. The frequency of enteric outbreaks and of botulism clearly points to a very general failure to appreciate the dangers of bacterially contaminated and spoiled food. Detailed suggestions for inspection of canned food are presented in this paper.

5. Responsibility for eliminating spoiled food from human consumption rests equally upon the packer, the dealer, and the person who prepares it for the table. Every one who handles food should be familiar with standards of quality, appearance, odor, and texture of the product, whether in bulk or in sealed containers.

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[3] Issued as *U. S. Dept. Agr. Bul. 1129*, Nov. 27, 1922.

[4] Published in *Am. Food J.*, **17**, Nov., 1922, 15.

NOTES FROM THE U. S. BUREAU OF MINES.*

TECHNOLOGY OF SLATE.

By Oliver Bowles.

THE writer recently completed a careful study of about sixty-five active slate quarries and finishing plants in Pennsylvania and Maine; New York and Vermont; Maryland-Pennsylvania, and Virginia.

The chief products of manufacture are roofing slates, blackboards and school slates, electrical switchboards, billiard tables, shower stalls, steps and various other forms of structural slate. Waste constitutes a very important problem in all slate quarry operations, the proportion of waste varying from 65 to 95 per cent. Much study was devoted to improvements, whereby waste could be partly eliminated, and to determine more extended uses for unavoidable waste. Experiments by industrial laboratories indicated that pulverized waste slate could be used to advantage as a filler in road asphalt mixtures, plastic roofing and flooring, and various other products. Many other uses of slate refuse are discussed. However, due to the difficulty of developing a wide market for waste slate, quarrymen should devote their attention primarily to means of eliminating waste to the greatest possible extent. Further details will be found in Bulletin 218, of the Bureau of Mines.

ROCK STRATA GASES IN MINES OF A NEVADA MINING DISTRICT.

By E. D. Gardner.

IRRESPIRABLE gases issuing from the rock formations are a source of expense and danger in some metal mines. There is a great variation in the composition of such gases and, as shown by recent sampling by the Bureau of Mines, the gas may consist mostly of carbon dioxide ("Rock Strata Gases in the Mines of the East Tintic Mining District," by G. E. McElroy, Bureau of Mines Serial 2275), or of methane ("Methane in California Gold Mines," by B. O. Pickard and E. D. Gardner, Bureau of Mines Serial 2303), or nitrogen, as in the present instance.

* Communicated by the Director.

A number of unventilated raises in some of the mines of a Nevada district contain accumulations of a high-nitrogen gas that will not support life or combustion. The raises are in different geological formations and in widely separated localities in the mining district. One of two raises in the same formation may be full of the gas and another nearby be free of it. Lives have been lost and a number of men have been overcome on entering unventilated raises in which the irrespirable gas had accumulated between shifts. Generally, however, the gas seems to "ooze" from the formation and to accumulate so slowly that its presence is not suspected at the time, but discovered after the raise is abandoned. Occasionally it issues from a newly cut crevice or fissure under considerable pressure and in large enough quantities to overcome or drive out men working in unventilated places. Further details are given in Serial No. 2427 of the Bureau.

REMOVAL OF SULPHUR FROM GASOLINE.

By D. B. Dow.

THE Bureau of Mines has completed an investigation of the practical operation of gasoline plants in the mid-continent field, in which gasoline containing objectionable sulphur compounds is treated for removal of the sulphur. When the need for such treatment first became obvious about 1920, in order to permit such gasoline to meet rigid export requirements, the Bureau of Mines first developed a suitable method and was largely instrumental in having it installed by the gasoline operators. The report on the present investigation, which deals with the costs and efficiencies of the treatment as applied in the different plants, will soon be available. Data were obtained on construction, accurate operating costs, and photographs of gasoline treating plants at Shidler, Oklahoma, and Kansas City, which are claimed to be the largest plants of their type in the world.

STUDY OF NEW ALBANY SHALE.

By John R. Reeves.

IN 1921, a section was bored with a core drill by the Louisville Cement Company, through the New Albany, Indiana, oil shale, in Clark County, Indiana. The shale formation was struck at a

depth of 4 feet 11 inches and was found to have a total thickness of 98 feet 5 inches. It was found that the upper 35 feet and the lower 20 feet of the formation are the richest while the lowest yield was obtained from near the middle of the formation. The average yield for the entire formation at the location of this drilling is 8.3 gallons per ton. The average yield for the upper 50 feet is 11.6 gallons. Between 50 and 60 feet, the yield is very low, while from 60 to 98 feet it averages 7.0 gallons per ton. The New Albany formation constitutes the principal oil shale deposit of Indiana and outcrops in the southeastern part of the State, between North Vernon and New Albany. The outcrop district, running north and south, is about 50 miles long and from 5 to 15 miles wide. The same shale also outcrops in the northwestern part of the State, along the banks of the Wabash River and its tributaries in White and Carrol Counties in the vicinity of Monticello, Delphi, and Rockfield. The southeastern or principal outcrop district covers parts of Jennings, Jefferson, Jackson, Scott, Clark and Floyd Counties. This district extends south into Kentucky, the New Albany shale being coterminus with the Devonian oil shale of that State. Further details are given in Serial 2425, Reports of Investigations.

Breakage of Watch-springs.—S. R. Williams, of Oberlin College, has investigated the cause of the spontaneous breaking of main-springs in watches, a common and annoying incident. It appears that watch repairers are inclined to the view that such breakages are seasonal, occurring principally in the warmer months. Williams was permitted to examine the records over several years of two firms doing a large repair business, and on plotting the results found in both cases a peak in summer fairly coincident with the peak of the graph showing the occurrence of thunder storms. There was, however, in both cases, a slight dip about mid-July, which has been ascribed to the absence of many persons on vacation. Herman Seemann, a pupil in advanced standing in the department of physics at the College, made experiments in the matter, and the results indicate that the breakage is not due to heat but to moisture. Williams thinks that the moisture acts by starting rusting points which weaken the spring at those points. In an experiment, in which fifty-six samples were tried, equally divided between two well-sealed jars, one containing dry and the other moist air, seventeen springs broke in the latter and none in the former. Seemann also found that oiling the spring diminishes very markedly the liability to break. H. L.

The Effect of the Magnetic Field on the Absorption of X-rays. J. A. BECKER. (*Phys. Rev.*, August, 1922.)—"It was hoped that an applied magnetic field would orient the ultimate magnetic particle and that this shifting would result in a measurable change in the absorption of X-rays. A study of this effect would throw a new light on the nature of the ultimate magnetic particle and on its function in the atom." It was supposed that the result would be small. Hence a sensitive method was devised, correct to a few parts in 100,000. Two beams of X-rays from the same Coolidge tube were admitted into two identical ionization chambers of cylindrical form filled with methyl bromide and connected by a glass tube to insure the existence of the same pressure in both. The casing of one chamber was connected to the positive terminal of a battery while that of the other chamber was joined to the negative terminal. The middle point of the battery was earthed. The entrance of the X-rays into the respective chambers was followed by the ionization of the gas and by a consequent accumulation of charges upon metal rods running along the axes of the cylinders. In one chamber this charge was positive and in the other negative. Both of these rods were joined to the leaf of a Bumstead electroscope. If everything in the path of one beam is exactly equivalent to the corresponding feature in the path of the other, just as much positive electricity will be found on the rod of one chamber as there is negative on the rod of the other and the leaf, joined to both rods, will not be affected. To bring about this state a variable slit was placed in the path of one beam and the beam passing through it was regulated so as to produce a minimum motion of the leaf of the electroscope. This adjustment was made when there was in the path of each beam a specimen of the material to be examined. The specimen in the beam without the slit was between the poles of a powerful electromagnet. Upon the application of the magnetic field the strength of the beam emerging from the specimen in its path was changed. This caused a change in the ionization within the chamber and in the electric charge and, finally, in the motion of the leaf. What is sought is a knowledge of the change in the absorption of the beam by the specimen upon the turning on of the magnetic field. This can be calculated from the change in the aperture of the slit necessary to produce the same motion of the leaf.

The results were not the same when the magnetic lines of force were perpendicular to the beam as when they were parallel to it. In the case of iron both directions of the field cause a decrease in the absorption coefficient for X-rays, while for copper, nickel, aluminum and platinum an increase is produced. With carbon and zinc an increase is caused by one direction of the field and a decrease by the other. The field employed was about 18,000 gauss. Even with this the changes observed in the absorption of rays of wave-length .3 Angström unit were small in all cases. G. F. S.

THE FRANKLIN INSTITUTE.

(Proceedings of the Annual Meeting held Wednesday, January 17, 1923.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, January 17, 1923.

DR. WALTON CLARK, President, *in the Chair.*

The Board of Managers submitted its report. The report recorded the elections to membership of:

Charles S. Chrisman, Esq., Engineer, United Gas Improvement Company, 1401 Arch Street, Philadelphia, Pennsylvania;

William H. Kavanaugh, Esq., M.E., Professor of Experimental Engineering, University of Pennsylvania, Philadelphia, Pennsylvania;

Lewis F. Moody, Esq., B.S., M.S., Consulting Engineer, The William Cramp and Sons Ship and Engine Building Company, Richmond and Norris Streets, Philadelphia, Pennsylvania;

J. H. Mull, Esq., Shipbuilder, President and General Manager, The William Cramp and Sons Ship and Engine Building Company, Richmond and Norris Streets, Philadelphia, Pennsylvania;

Horace C. Porter, Esq., Ph.D., Consulting Chemical Engineer, Professional Building, 1833 Chestnut Street, Philadelphia, Pennsylvania;

Harvey Birchard Taylor, Esq., Vice-president, The William Cramp and Sons Ship and Engine Building Company, Richmond and Norris Streets, Philadelphia, Pennsylvania;

a lecture before the Stated Meeting December 20, 1922, by

W. F. G. Swann, D.Sc.,
Professor of Physics,
University of Minnesota,
Minneapolis, Minnesota,

on "Unsolved Problems of Cosmical Physics";

and additions to the library by gift, 116 volumes and 42 pamphlets; by purchase, 12 volumes.

The tellers of the election, Messrs. Jennings, Leffmann and Picolet, reported the ballots cast for President, Vice-president, Treasurer and members of the Board of Managers showed that the following gentlemen were elected to the respective offices indicated:

Walton Clark, President (to serve one year); W. C. L. Eglin, Vice-president (to serve three years); Benjamin Franklin, Treasurer (to serve one year); Managers—Gellert Alleman, G. H. Clamer, Theobald F. Clark, Walton Forstall, Benjamin Franklin, Harry F. Keller, George D. Rosengarten, William Chattin Wetherill (to serve three years); J. T. Wallis (to serve two years); J. Bartleman Klumpp (to serve one year).

The President read the annual report of the Board of Managers for the fiscal year ending September 30, 1922, commenting upon the reports of the various standing committees of the Institute and of the Board of Managers.

He then recalled that the Institute was meeting on the two hundred and seventeenth anniversary of the birthday of Benjamin Franklin and recognized Mr. James S. Rogers, who made the following remarks:

"Mr. President, Ladies and Gentlemen: It would be a pleasure to speak anywhere of Franklin, but particularly so in the presence of members of this Institute bearing his honored name. And it is most appropriate to do so standing before the Sully 'bust' portrait of him hanging on the wall here, and beside our treasured tools of his trade and instruments of his scientific toil—here in this hall where we feel the power of his personality pulsating through the ages, pick it up, amplify it as much as we can, and relay it on to future generations.

"In a few minutes during which the regular order of business may be encroached upon, it would be impossible to mention the great achievements of Franklin. And it would be unnecessary to do so, as you are all familiar with them.

"So I will confine myself to a few things of a general nature, which set out in a broad way his spirit and the influence of his life and works.

"The world, through the ages, in varying degree with different peoples, has largely been dominated by the religious mind. In so far as the religious mind has been of deep, true, spiritual insight, it has been the great light of the world, and the greatest beacon on the pathway of progress. In so far as it has surrendered itself to ignorance, superstition, and bigotry, it has been a hindrance to progress.

"The world has also, particularly in certain countries and at certain times, been greatly lead by the legal mind. In so far as this legal mind, including, of course, the judicial mind, has had broad vision, looking forward as well as backward, it has been one of the greatest influences in social development, probably the greatest influence next to the religious mind, with the possible exception of the mind influence of the noble teaching profession. But in so far as it has too much looked backward to precedent, and delighted in technicalities rather than substance, it has hindered rather than helped.

"And always there has been the influence of the business mind, with the business man trying to square his conduct with both the precepts of religion and the commands of law; and giving valuable object lessons to both the religious and the legal mind in applied religion and ethics in daily life.

"In recent generations there has grown into almost dominating prominence the scientific mind; the mind that inquires before it accepts, that seeks to know, that looks forward more than backward, that builds constructively and works for the betterment of human conditions. It clears away from the religious mind the befogging clouds of mere superstition, and breaks down the barriers of bigotry. It questions the edicts of the legal mind, and bids it free itself from the entanglements of outgrown precedent, that it may see changes which have taken place, and provide accordingly. It supplies the business man with the means of great works. And yet it, too, has its faults, and one word of

caution in lauding it is necessary. It sometimes in conceit at its own accomplishments fails to see, above and beyond, the Divinity which established the cosmic order, and all the little that has been discovered of it.

"It is one of Franklin's greatest services that in the early years of really scientific research he gave a splendid and inspiring example of the spirit, methods and accomplishments of the scientific mind.

"Of this a simple illustration may be taken, for simple illustrations are often most illuminating; and there is one at hand suggested by the tablet you have noticed in the hallway to this room, erected to Franklin by the Stove Manufacturing Industry of the United States, and commemorative of his invention of the Pennsylvanian Fireplace, which in its subsequent portable form has become known as 'The Franklin Stove.'

"In his pamphlet describing this invention Franklin shows forth most interestingly the spirit and methods of the scientific mind.

"He begins with an examination of the prior art and existing methods of heating houses. After pointing out their merits and defects he takes up particularly the large open fireplace, with huge chimney, then in general use, burning cord wood. He points out their excessive and wasteful consumption of wood; and that if this is persisted in it will in time unduly deplete the forests and burden later generations with increased cost of wood. In this you will see his foresighted thought for his fellowmen in later years.

"He shows that in such fireplaces a large part of the heat goes to waste up the chimney place; for air when heated rarifies and rises. And as that truth was not so generally known as now, he gives two simple experiments by which, if you doubt it, you can prove it.

"He points out that the air which goes up the chimney must be replaced, and that this brings air whistling in with unpleasant noise through the cracks of doors and windows; but this does not supply enough air and smoke comes out into the room. To furnish enough air and draft, he says it is customary to open doors or windows. That brings in so much cold air that the family draw up close to the fire, frequently without room enough around it for them all, and they roast in front and freeze in back. To overcome this, high-back settles are built.

"He takes up objections which some make to living in heated rooms, alleging that it is unhealthy and subjects one to taking cold upon going out. As opposed to this, he sets forth the wonderful power of the body to accommodate itself to different temperatures; among other illustrations points out to his readers that they sleep in warm feather beds, but jump out in the morning into cold rooms, without ill effects.

"He takes up and answers objections to iron stoves, that when heated they give off noxious and poisonous gases, and offensive odors. He cites the good health of those who work around heated iron, as blacksmiths and workers in iron foundries. He shows that bad odors from iron stoves come not from heated iron, but from untidy housewives permitting the stoves to become covered

with grease and dirt; also that some men are filthy enough to spit on hot stoves to see the sizzle, until such a stench arises in a small room that the nostrils cannot stand it.

"He shows the healthfulness of fresh air, and the advantages of bringing fresh air into the house and heating it to warm the rooms.

"In all of this you will see the careful method of the scientific mind in the observation of facts, and reasoning from observed facts.

"He sets forth with an abundance of illustrative plates, his Pennsylvanian fireplace, with careful instructions for its proper erection.

"In this fireplace he provides an air chamber, against the front of which the fire is built, and of a construction so arranged that the draft draws the flame to the top of the air chamber, across the top and down the back of it, under a false back in the chimney, and then up the chimney. This supplies heat on three surfaces of the air chamber.

"A duct is provided under the floor bringing air from outside the house to the air chamber; and openings in the two opposite ends of this chamber permit the heated air to escape into the room; provision being also suggested for carrying heated air to the room above, if desired. He thus provided in principle a modern hot-air plant, for taking in and heating fresh air.

"Difficulties in getting mechanics to properly erect this most excellent fireplace, gradually led to its abandonment and the substitution of the portable forms of so-called Franklin stoves.

"Another characteristic of Franklin, which may be mentioned in this broad general way, was his devotion to work. From the time when at the early age of ten years he first began to help his father, he worked and toiled for about seventy years of a long and fruitful life. Much of this effort was devoted to constructively bettering the condition of his fellowmen.

"There are many to-day whose remedies for social ills are destructive, and who want others to work in order that they may eat and be clothed and enjoy lazy ease—if lazy ease can be enjoyed. But Franklin recognized the struggle for existence, the workings of the inexorable laws of life, and that sooner or later neglect of the law of work brings realization that if we would eat we must work.

"Finally, let us consider Franklin's spirit and purpose in his life of work. He applied along scientific and economic lines the abilities of his mind and his hours of labor to broadening human knowledge and benefiting his fellowmen, not alone of his own generation, but with foresight and consideration for generations to come. And to this we must add his long, conspicuous and most able services in public capacities in trying colonial and revolutionary days—services so present in your minds that they speak for themselves, and evoke your gratitude.

"If we can absorb somewhat of spirit and purpose from the Franklin atmosphere which pervades this venerable Institute, the contemplation of his life will be to us an inspiration to work and serve."

The paper of the evening was presented by Dr. E. A. Eckhardt, Physicist, Bureau of Standards, Department of Commerce, Washington, D. C., on "Building Acoustics." The chief problems of acoustics which are encountered

in the construction and furnishing of public buildings and homes were outlined and it was pointed out that with the development of fireproof building construction the requirements of satisfactory acoustical conditions have been increasingly difficult to meet. The degree to which our present knowledge permits predetermination of acoustical properties of structures from their design was discussed. The direction and extent of present-day research along building acoustic lines was also reviewed. The subject was illustrated by lantern slides.

A unanimous vote of thanks was extended to Doctor Eckhardt for his paper. Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, January 3, 1923.)

HALL OF THE INSTITUTE,
PHILADELPHIA, January 3, 1923.

DR. JAMES BARNES *in the Chair.*

The following reports were presented for final action:

No. 2801 and No. 2802 — The Franklin Medal. The Franklin Medal to General G. Ferrié, Chief Signal Officer, French Army, Paris, France, and Dr. A. A. Michelson, Professor of Physics, University of Chicago, Chicago, Illinois.

The following reports were presented for first reading:

No. 2763: "Sip" Universal Measuring Machine.
No. 2785: Maxon Pre-Mix Burner.
No. 2798: Adjustable Hinge.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, January 10, 1923.)

RESIDENT MEMBERS.

PROF. WILLIAM H. KAVANAUGH, University of Pennsylvania, Philadelphia, Pennsylvania.

MR. LEWIS FERRY MOODY, William Cramp and Son's Ship and Engine Building Company, Richmond and Norris Streets, Philadelphia, Pennsylvania.

MR. J. HARRY MULL, William Cramp and Son's Ship and Engine Building Company, Richmond and Norris Streets, Philadelphia, Pennsylvania.

DR. HORACE C. PORTER, 1833 Chestnut Street, Philadelphia, Pennsylvania.

MR. H. BIRCHARD TAYLOR, William Cramp and Son's Ship and Engine Building Company, Richmond and Norris Streets, Philadelphia, Pennsylvania.

NON-RESIDENT.

MR. CHARLES CHRISMAN, 405 West Miner Street, West Chester, Pennsylvania.

CHANGES OF ADDRESS.

MR. JOHN H. BARR, Barr-Morse Corporation, 149 Church Street, New York City, New York.

MR. A. W. K. BILLINGS, in care of Canadian and General Finance Company, Ltd., 357 Bay Street, Toronto, Canada.

MR. W. F. GRAHAM, Curtis Bay Copper and Iron Works, Curtis Bay, Baltimore, Maryland.

MR. B. B. MILNER, Imperial Hotel, Tokyo, Japan.

LIBRARY NOTES.

PURCHASES.

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Photograms of the Year 1922.

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